LOTIC ECOREGIONS OF NEW ZEALAND

A thesis

presented for the degree of

Doctor of Philosophy in Zoology

in the

University of Canterbury

Christchurch

New Zealand

by

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University of Canterbury

1994

Abstract

A lotic ecoregion classification for New Zealand was developed based on six macro-environmental variables; vegetative cover, bedrock geology, soils, relief, rainfall normals, and Meteorological Service Climatic Regions. South Island maps of these variables were merged, and a new composite ecoregion map generated using a GIS. Twenty-five ecoregions are proposed, 13 in the North Island and 12 in the South Island. The water chemistry and benthic invertebrate assemblages of 100 small headwater streams within 10 of the South Island ecoregions were investigated to test the validity of my proposed ecoregions. Most ecoregions could be recognised by characteristic assemblages of invertebrates. The "pristine" forested ecoregions of Westland, North-west Nelson, North-east Nelson, and the South-east Forest had high taxonomic diversity, numerous endemic species, and faunas dominated by mayflies and stoneflies. In contrast, the anthropogenically modified pastoral ecoregions of the East Coast Plains, Central Otago, and the Southland Plains had streams with very similar invertebrate assemblages, low taxonomic diversities and a predominance of molluscs, oligochaetes and dipterans. Streams in these ecoregions could only be distinguished on the basis of differences in the abundances of several common taxa. Water chemistry distinguished between ecoregions less successfully, however, South-east Forest and North-east Nelson streams in particular, were distinctive. Differences in the geology of catchments, in particular the presence or absence of alluvia, mudstone, soft sedimentary rocks and volcanic rocks have important influences on the water chemistry of South Island streams. An investigation undertaken in one ecoregion indicated the need for an ecoregion classification to take account of variations in land use. Thus, both invertebrate assemblages and water chemistry differed in streams draining catchments with four kinds of land use. Native forested streams had the highest taxonomic richness and faunas dominated by mayflies and stoneflies. Streams in exotic forest and scrubland catchments had progressively fewer taxa, particularly mayflies and stoneflies; streams in pastoral land had even fewer taxa,

mayflies and stoneflies were rare, and molluscs and oligochaetes predominated. In summary, my ecoregion and land use investigations indicate that three macro-environmental factors; biogeographical events, climatic conditions, and vegetative cover/land use, are of primary importance in determining invertebrate assemblage structure and regional differences in the biotas of small, South Island streams.

CONTENTS

NB A fold out flap with a South Island ecoregion map, and list of ecoregions and their codes is located on the last page to enable the reader to refer to the ecoregions while reading the text.

Chapter 1

Development of Lotic Ecoregions

Introduction

Ecological regions can provide a suitable basis for understanding and studying the components of ecosystems, and gaining a holistic view of processes within them. They enable us to investigate how biological communities interact with their environments, and to assess the effect of changes that occur across large geographical areas (Hawkes et al. 1986). The development of a nationwide river classification system within an ecoregion framework has enormous potential for biologists, conservators, and water managers.

Several terrestrial-based classifications have been suggested for elements of the New Zealand biota. Simpson (1982), Timmins & King (1984) and McEwen (1987) proposed regional ecological frameworks based on geological, climatic, and vegetation features. Forster (1954) proposed a regional classification for New Zealand harvestmen (Arthropoda: Opiliones) species, while Lee (1959) suggested a nationwide classification based on the distributions of earthworms (Oligochaeta: Megascolecidae & Lumbricidae); and Crosby et al. (1976) proposed 29 rather arbitarily defined regions for entomological locality data. The few freshwater classifications proposed have been used for defining the hydrological properties of streams and rivers for descriptive and predictive purposes. Toebes & Palmer (1969) divided the country into 90 hydrological regions on the basis of rainfall, bedrock geology, and slope, whereas Beable & McKercher (1982) suggested nine flood frequency regions using mean flow data.

The first river classification incorporating a wide range of abiotic and biotic criteria resulted from a nationwide survey by Biggs et al. (1990), and included flow variability, water quality, periphyton and faunal data. Biggs et al. (1990) proposed dividing New Zealand into five ecoregions, with the South Island representing a single region. However, large areas of

the South Island including the West Coast, Fiordland, Banks Peninsula, Catlins and Stewart Island were not included in their study.

Recent North American river classification systems have acknowledged strong associations between terrestrial and aquatic ecosystems, and as a consequence, considerable emphasis has been placed on geographical features that influence catchment conditions (Likens & Bormann 1974, Hynes 1975, Lotspeich 1980, Lotspeich & Platts 1982, Brussock et al. 1985, Frissell et al. 1986, Naiman et al. 1990). Similarly, several biologists have based classifications of fish distributions on drainage basin criteria (e.g. Miller 1958) and physiographic regions (e.g. Trautman 1981). Nevertheless, drainage basins alone do not account for all changes in water characteristics resulting from alterations in surrounding land use. Thus in Quebec, Legendre & Legendre (1984) demonstrated that climate, geomorphology and vegetation patterns were more useful than river basins in explaining present day fish distributions because of postglacial changes in drainage.

Two main strategies have been adopted to identify aquatic ecoregions. Firstly, regions can be identified by collecting and analysing large quantities of hydrological, chemical and biological data (e.g. Savage & Rabe 1979, Pflieger et al. 1981, Legendre & Legendre 1984, Hawkes et al. 1986, Biggs et al. 1990). To be effective this approach requires large databases, and even then it is difficult to extrapolate results to other geographical regions. Alternatively, aquatic ecoregions can be defined by correlating macro-environmental factors with appropriate biotic data (Lotspeich 1980). This latter approach is considered to provide a more holistic perspective on aquatic ecosytems (Rowe & Sheard 1981, Bailey 1983), as broad-scale patterns in climatic and geomorphological data are used to explain patterns (Warren 1979, Lotspeich 1980). Intrinsic to this approach is the assumption that ecosystems and their components show regional patterns that are reflected in combinations of different biogeographical conditions (Larsen et al. 1986, Omernik 1987). The method has been used in North America for the design of Land Resources Regions and Major Resource Areas of the United States (USDA Soil Conservation Service 1981) based

on soil, climate, water availability, vegetation type and land use criteria. The same technique was adopted by Bailey (1976, 1981) to develop an ecoregion map of the USA, and Omernik who produced ecoregion maps of the Pacific Northwest and the entire United States (Omernik & Gallant 1986, Omernik 1987) by integrating mapped data on soil, land-surface form, potential natural vegetation, and land use (Anderson 1970, Hammond 1970, Kuchler 1970). Similarly, in New Zealand the Land Resource Inventory categorizes areas on the basis of soil type, geology, vegetation and slope (NWASCO 1975-79).

The ecoregions proposed by Bailey (1976) and Omernik (1987) have been tested extensively using diverse data sets, and validated within several States across the U.S.A. Olson et al. (1982) used a geoecological database (including climatic, geographical and biological data) to test Bailey's Laurentian mixed-forest province, while Rohm et al. (1987) found that a high level of correspondence occurred between water chemistry and fish distributions in small Arkansas streams, and Omernik's ecoregions. Similarly, Larsen et al. (1986, 1988) found a high correlation between major ion concentrations and nutrient richness in stream waters and the five ecoregions in Ohio. Heiskary et al. (1987) found similar correlations between lake water quality and Minnesota ecoregions, and physical habitat measurements, water chemistry, benthic invertebrate assemblages and fish communities were associated by multivariate analysis with eight ecoregions in Oregon (Hughes et al. 1987, Whittier et al. 1987). Finally, Lyons (1989) found that four ecoregions in Wisconsin had broad differences in their fish communities although individual streams showed some variability and regional overlap.

The aim of my study was to develop a lotic ecoregion classification for New Zealand based on a range of climatic and geomorphological factors. The distinctiveness of the South Island ecoregions defined in this way was then evaluated by surveying the water chemistry and benthic communities of 100 streams considered to be characteristic of the ecoregions. Finally, the importance of local land use differences on ecoregional characteristics was evaluated in one ecoregion, and following this a hierarchical subdivision of ecoregions is

proposed.

Identification of ecoregions

Ecoregions were defined by comparing climatic and geomorphological parameters that on the basis of past experience were considered likely to influence stream biota. Lotspeich (1980) suggested that stream communities evolve in response to climatic conditions acting on the geological landscape. Biggs et al. (1990) proposed further that climate, vegetation, geology and human activities all influence the structure and functioning of river ecosystems; their model with the addition of a biogeographical component was used as the basis of my classification (Fig. 1.1). The primary tenets of the Biggs et al. model are that geology, relief, climate and biogeographic conditions are the "driving" factors that influence vegetation, and land use, and that all of these factors, both directly and indirectly, influence water chemistry, stream hydrology and lotic biota.

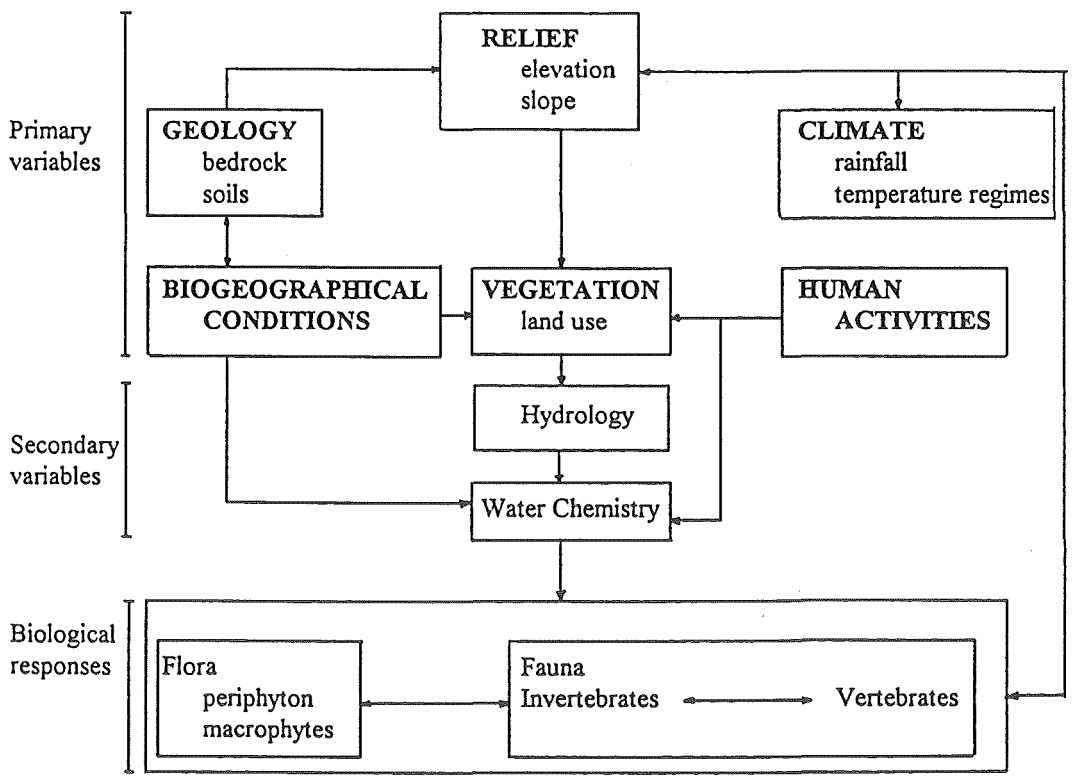


Figure 1.1 A hierarchical model showing the major variables influencing water chemistry, the flora and fauna of stream ecosystems, and the linkages between them (Modified form Biggs et al. 1990).

I used six parameters to identify ecoregions and establish their boundaries. They were, New Zealand Meteorological Climatic Regions, rainfall, relief, vegetation, soils, and geology. New Zealand Climatic Regions were defined by the Meteorological Service (1983), and were used to provide an indication of comparable hydrological, temperature, and climatic extremes across the country (refer Appendix 1). Rainfall normals (1951-80) representing the mean annual rainfall averaged over a 30 yr period were included to indicate potential differences in stream flows between streams in each ecoregion. Vegetative cover was used as an indicator of present land use patterns, and soil type was included to give a perspective of past regional climate, topography (relief and slope), vegetation and bedrock material, as well as to indicate potential groundwater chemistry. The main soil categories used in this study, and the primary factors affecting their formation are shown in Table 1.1. Bedrock geology was measured because of its effect on water chemistry and on catchment and channel morphology. Lastly, elevational data was considered as a surrogate of temperature (particularly seasonal extremes).

The South Island ecoregion map was constructed using the Geographic Information System (GIS) package TERRASOFT (refer Appendices p150 for specifications)(Digital Resources 1987). GIS is a computer software system which enables information from maps, descriptive databases, satellite imagery, and aerial photographs to be stored, overlayed, manipulated and integrated (Congalton & Green 1992). This enables a geographical database

Table 1.1 Factors that influence soil formation in New Zealand (after Molloy 1988)

Soil group	Age	Bedrock	Climate	Topography	Vegetation
Yellow-brown pumice & loams		*			
Brown granular loams		*			
Recent alluvial soils	*			*	
Gley soils				*	
Yellow-brown sands		*			
Yellow-grey & yellow-brown earths		*			
Podzols, gley podzols			*		*
Recent volcanic	*	*			
Organic				*	*

to be constructed which can incorporate both physical and biological data. The great advantage of GIS over other database and mapping software is its ability to store both spatial data, such as land use information, at a variety of scales, and specific point source information, such as the composition of the fauna in a particular reach of a stream (Green 1992).

TERRASOFT was used to overlay digitized linework from a series of 1:1,000,000 and 1:2,000,000 maps. As databases containing map linework of the six variables selected. did not exist, the linework was digitised into the computer by hand. Firstly, six GIS "layers" were created corresponding to the six climatic and geomorphological variables selected, Each of these was then divided into broad classes of climatic or geomorphological conditions, for example, the original number of vegetative cover classes produced by Newsome (1987) was reduced from 47 to four in my vegetation map (Table 1.2). This amalgamation of classes reduced the number of polygons (or regions) to a number that could be manipulated readily by the software (i.e. approximately 20-30 "polygons" or regions per map). To enable distinct regions to be created, mapped linework from two maps, which were paired arbitrarily, were overlayed at a time. A total of six "parent" maps representing bedrock geology (NZ Geological Survey 1972a,b), soils (NZ Geological Survey 1973a,b), Rainfall normals 1951-1980 (NZ Meteorological Service 1985), NZ Climatic Regions (NZ

Table 1.2 The broad categories generalised from the six component maps and used to develop the ecoregion maps from Lands & Survey, NZ Meteorological Service (Climatic Regions and rainfall), and NZ Geology Survey maps.

Climatic Regions	Elevation (m)	Vegetation Classes	Soils Classes	Geology (Time periods)	Rainfall (mm)
A_1-A_2	0-299	Forest	Yellow brown loams & pumice	Cenozoic	0-599
B_1-B_2	300-999	Scrub	Brown granular loams	Mesozoic	600-1199
C_1-C_3	1000+	Tussock/	Gley soils	Paleozoic	1200-4799
D_1-D_2		pasture	Yellow-brown & yellow-grey earths		4800+
E_1-E_2		Improved	Podzols, gley podzols		
F_1-F_2		grasses	Recent alluvial		
F_1-F_3			Recent volcanic		
G_1-G_2			Organic		

Meteorological Service 1983), relief (NZ Lands & Survey 1989), and vegetation cover (Newsome 1987) were overlayed. Initially, TERRASOFT was used to overlay the linework from three pairs of "parent maps": bedrock geology and soil maps, rainfall normals and Climatic Regions, and relief and vegetation were paired. The result of this process was the production of three "daughter" maps each consisting of polygons characterised by their parent maps. The three "daughter" maps were then merged to produce a final "grandaughter" ecoregion map (Fig. 1.2). Merging and integrating maps produced numerous polygons which were reduced by removing areas of less than 1000 ha. TERRASOFT is unable to merge lines that are adjacent to each other but not touching, so this was done manually by redrawing new boundary lines half way between pairs of lines. Figure 1.3 provides an example of the overlay procedure, and shows the linework for the six component (parent) maps for the Banks Peninsula (PE) ecoregion. In this figure, the boundary between the East Coast Plains (EC) and Banks Peninsula ecoregions was defined by differences in relief (plains v. volcanic hills), land use activities (improved pasture v. mixed indigenous scrub and tussock), soils (yellow grey earths v. brown granular loams),

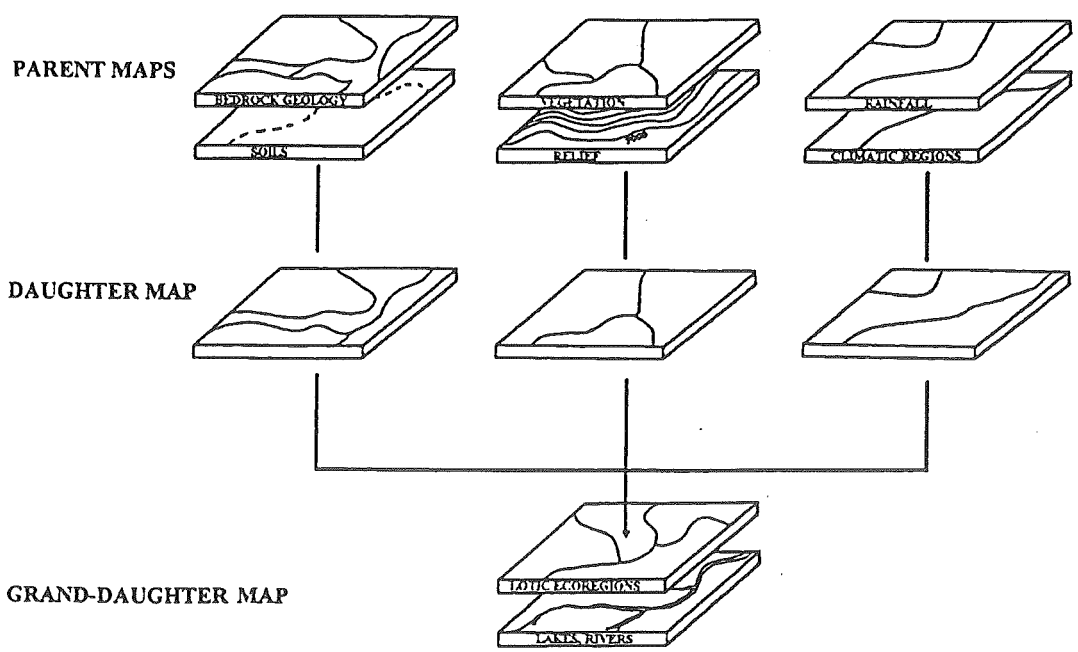


Figure 1.2 Ecoregions were defined by merging and generalising six "parent maps" to form three "daughter" maps. The three daughter maps were then merged to form the "grand-daughter" ecoregion map.

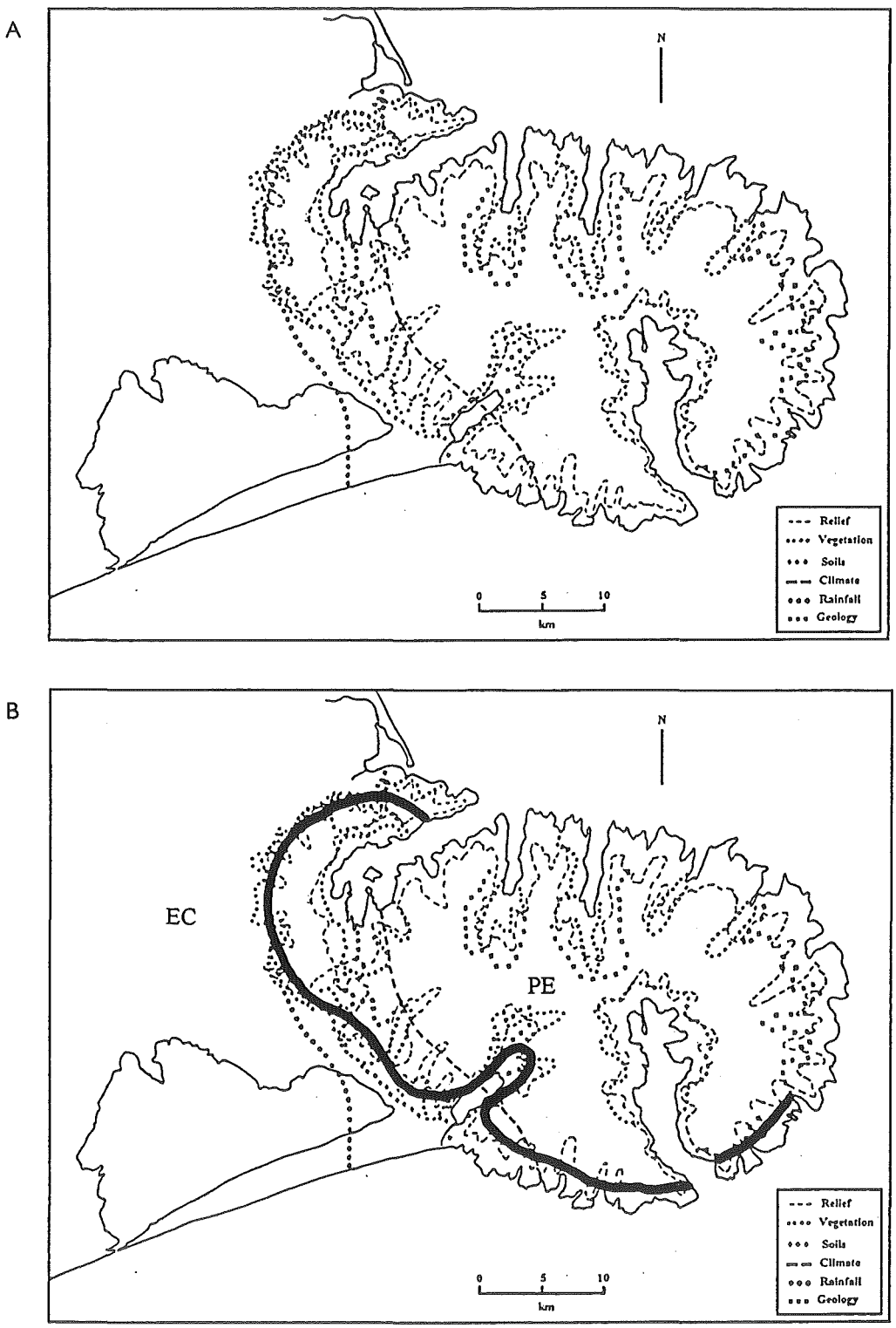


Figure 1.3 a) East Coast Plains (EC), and Banks Peninsula (PE) ecoregions showing linework from the six "parent" maps that were merged, and generalised to form the final ecoregion boundary, and b) the final PE - EC boundary, which although represented by a line is actually a zone 1 -2 km wide.

and climatic conditions (i.e. 400-1200 mm yr rainfall v. 1200-2400 mm yr). The final ecoregion boundary is not a discrete line but a transitional zone along the mid-points of overlapping linework from the component maps. The same protocol was used for the North Island, however, instead of using GIS, the six maps were merged by hand. The North Island is not as geologically complex as the South Island, and areas of native forest, exotic forest and grassland are more clearly defined in the North. Therefore, the number of polygons produced from each of the component maps was fewer than for the South Island. Furthermore, the final North and South Island maps at 1:1,000,000 scale do not show detail at the scale of individual catchments, therefore there was probably only a minor loss of accuracy in integrating and generalising linework by hand rather than using GIS.

Changes in vegetation and altitude were often associated with changes in rainfall isohyets. Because these two variables accounted for half of the component map data, they provided the most frequent indicators of ecoregion boundaries.

Ecoregions were identified by means of a name/descriptor and two letter code. Descriptors and codes were selected on the basis of familiar features or commonly used geographical names.

Ecoregions were colour-coded on maps. Where possible, colours that could be associated with the primary vegetation/land use characteristics of the ecoregion were chosen. Light green was used for plains, medium green for forest, dark green for rainforest, brown for scrub covered hill country, cloudy green for exotic forest, and white for alpine regions.

The Ecoregions

The North Island was divided into 13 ecoregions and the South Island into twelve (Fig. 1.4). Ecoregions ranged in size from approximately 900 to 12,000 km^2. Each was characterised by a suite of "typical" conditions associated with the six climatic and geomorphological variables (Table 1.3). In general, vegetation was the best delineator of regions as it was often associated with changes in altitude, rainfall, and to a lesser extent soil type. Ecoregions could sometimes be subdivided on the basis of differences in vegetation,

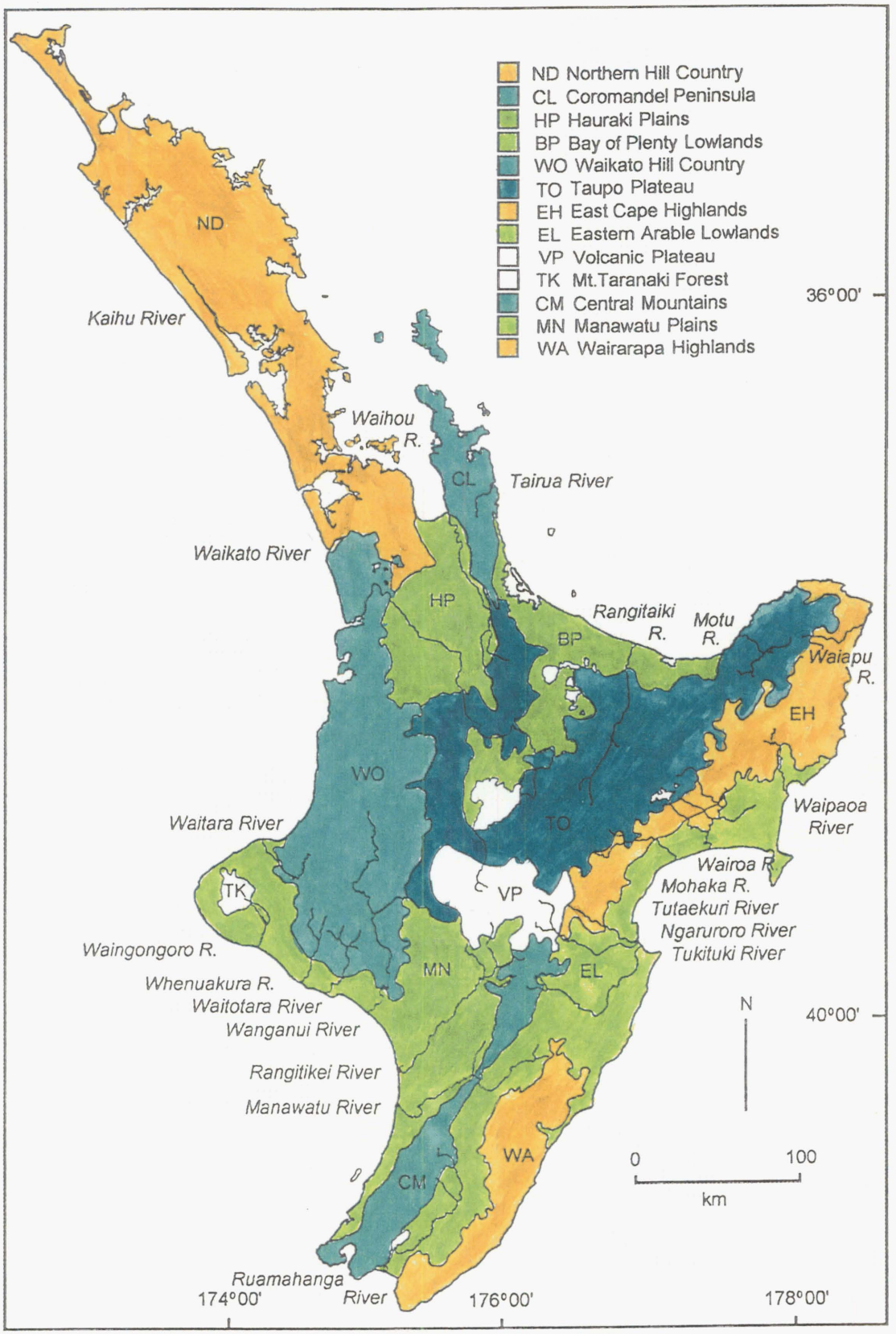


Figure 1.4 Lotic ecoregions recognised in the North and South Islands. Characteristic features of the the six climatic and geomorphological characteristics used in defining each ecoregion are shown in Table 1.3.

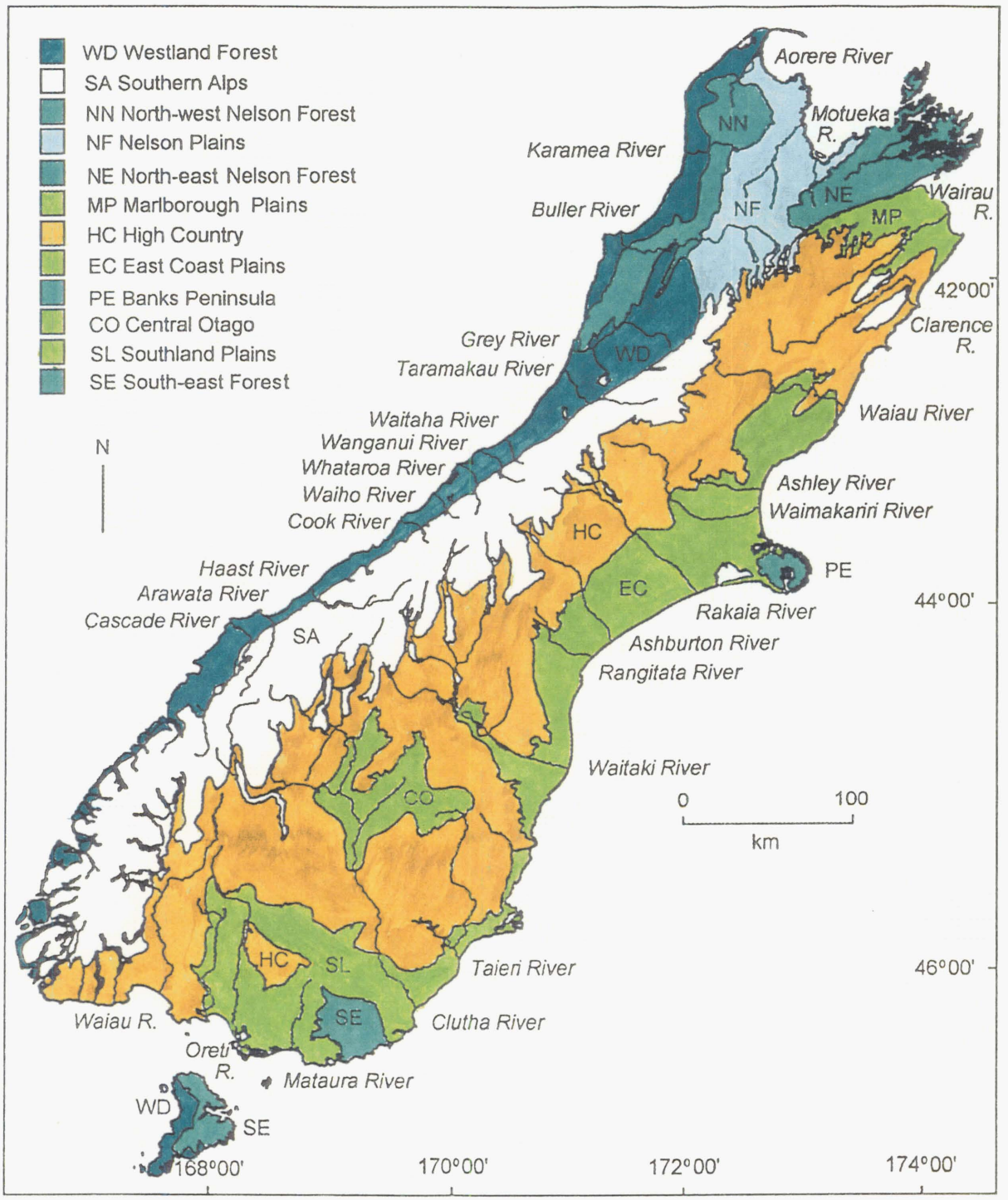


Figure 1.4 (continued).

Table 1.3 The 13 North Island and 12 South Island ecoregions recognised in this study. Characteristic features of the six climatic and geomorphological variables used to differentiate the ecoregions are indicated.

Code	Area	Climatic Region	Rainfall (mm)	Relief (m)	Vegetation	Soils	Geology
North Island							
ND	Northern Hill Country	A_1/A_2	800-2400	0-300	Mixed forest,grassland	Yellow-brown earths	Sandstone,siltstone
CL	Coromandel Peninsula	A_2	1600-3200	0-600	Podocarp/broadleaf forest & exotic forests	Brown-granular loams yellow-brown pumice	Andesite
HP	Hauraki Plains	A_1	800-1600	0-300	Improved pasture	Gley, yellow-brown loams	Alluvium, swamp & peat deposits
BP	Bay of Plenty Lowlands	B_1/B_2	1200-2400	0-600	Improved pasture,exotic forests	Yellow-brown pumice recent volcanic soils	Alluvium
WO	Waikato Hill Country	A_2	1200-3200	300-600	Pasture, podocarp-broadleaf forest	Yellow-brown earth	Sandstone, siltstone
TO	Taupo Plateau	M/B_2	1200-4800	300-1000	Exotic,podocarp-broadleaf & beech forest	Yellow-brown pumice	Sandstone, siltstone, ignimbrite
EH	East Cape Highlands	C_3	1200-2400	300-600	Grassland, scrub	Yellow-brown earths & pumice	Sandstone, siltstone
EL	Eastern Arable Lowlands	C_1/C_2	800-1600	0-300	Improved pasture	Yellow grey earths	Marine gravel, sandstone, siltstone
VP	Volcanic Plateau	M	2400-6400	600-2000	Alpine scrub, tussock	Bare rock, recent volcanic soils	Andesite, laharic colluvium
TK	Mt.Taranaki Forest	M	2400-6400	600-2000	Podocarp-broadleaf-beech forests	Bare rocks, Yellow-brown loams	Andesite, laharic colluvium
CM	Central Mountains	M/D_1	1600-6400	300-1000	Podocarp-broadleaf-beech forests	Yellow-brown earths	Sandstone, siltstone
MN	Manawatu Plains	D_1	800-1200	0-300	Improved pasture	Yellow-brown sands & yellow grey earths	Alluvium, marine sandstone, siltstone
WA	Wairarapa Highlands	C_3/C_1	1600-3200	300-600	Grassland, scrub	Yellow-brown & yellow grey earths	Sandstone, siltstone

Table 1.3 (continued) The 12 South Island ecoregions recognised in this study. Characteristic features of the six climatic and geomorphological variables used to differentiate the ecoregions are indicated.

Code	Area	Climatic Region	Rainfall (mm)	Relief (m)	Vegetation	Soils	Geology
South Island							
NN	North West Nelson Forest	M	2400-9600	0-2000	Beech/podocarp	Gleyed podzols	Greywacke, granite
NF	Nelson Plains	B_1	0-2400	0-1500	Beech, Exotic, Horticulture	Assorted earths	Gravels, limestone,greywacke
NE	North East Nelson Forest	C_1/D_2	1200-4800	0-2000	Beech/lowland podocarp	Podzols	Greywacke, argillite
MP	Marlborough Plains	C_2	600-1200	0-300	Improved pasture	Yellow-grey earths,recent	gravel, marine sandstone, siltstone
WD	Westland Forest	E_1	2400-4800	0-300	Podocarp	Podzols, recent	Greywacke, glacial gravels
SA	Southern Alps	M	>4800	>800	Alpine scrub, rock	podzols, earths,rock	Greywacke, schist
HC	High Country	F_2	600-2400	300-2000	Tussock, grassland, scrub	Yellow brown/grey earths	Greywacke, argillite
EC	East Coast Plains	F_1	400-1200	0-300	Improved grasses	Yellow grey earths, recent	Glacial gravels
PE	Banks Peninsula	C_1	1200-2400	0-1000	Grassland, scrub	Brown granular loams & clays	Volcanic basal flows
CO	Central Otago Basin	F_3	0-600	0-600	Pasture, tussock	Brown grey & yellow brown earths	Alluvial gravels, metamorphised
SL	Southern Plains	G_1/G_2	600-1200	0-300	Improved grasses,	Yellow grey/brown earths	Aggradation, gravels, greywacke
SE	South Eastern Forests	$F_2/G_1/G_2$	1200-2400	0-800	Lowland podocarp, limited beech	Yellow brown earths, Organic, podzols	Sandstone ,siltstone

climate and soils. For example, much of the High Country ecoregion is dominated by short tussock (*Festuca* and *Poa* spp.) and snow tussock (*Chionochloa* spp.), although extensive beech forests (*Nothofagus* spp.) occur along the Puketeraki, Poulter, and Dampier Ranges in the headwaters of the Waimakariri and Ashley Rivers. These forested areas also have higher rainfall and higher mean temperatures than the more southern parts of the High Country ecoregion (e.g. the Hokonui and Taringatura Hills), and it could be argued that they represent a subecoregion. A hierarchical design for ecoregion subdivisions is discussed in Chapter 6. Several regions were clearly distinguishable because of the uniformity of their characteristics, e.g. East Coast Plains of the South Island (EC), and Mt. Taranaki (TK). Others were less distinctive, and included complex combinations of vegetation, geology and soils, e.g. Northern Hill country of the North Island (ND), and North-east Nelson Forest (NE). Details of these South Island ecoregions are provided in Chapter 2.

Discussion

Several classifications and subdivisions of New Zealand have been suggested to describe the distributions of elements of the terrestrial flora or fauna (Forster 1954, Lee 1959). Forster (1954) divided the country into nine regions based on the distribution of harvestmen (Opiliones), whereas Lee (1959) designated 11 regions based on earthworm distribution. Similarities between Lee's regions and those I am proposing include the recognition as discrete entities of Banks Peninsula, Stewart Island, and the East and West Coast regions of the South Island. The factors that influence semi-aquatic earthworms, in particular, soil chemistry (including temperature and moisture) are influenced by vegetation, climate and bedrock geology, and are also likely to have significant effects on fully aquatic stream faunas. Ecological regions defined recently by Simpson (1982), Timmins & King (1984) and McEwen (1987) are defined primarily on the basis of differences in geology, landform, climate, soil, and the extent of remaining indigenous vegetation. Because the 79 regions they defined were principally for use with terrestrial fauna and flora, rivers and

streams were often used as regional boundaries; consequently, they are considered unsuitable for river classification purposes (Collier & McColl 1992).

The recent survey of 100 rivers nationwide by Biggs et al. (1990) was the first attempt to classify New Zealand river systems, and included data on flow variability, water quality, periphyton, and fauna. They suggested that the North Island might be divided into four ecoregions (Fig. 1.5), the northern, including Northland, Waikato and Taranaki; the central, including the volcanic plateau; the eastern encompassing East Cape, Hawke Bay, and Wairarapa; and the south-western including Wellington and the Tararua Ranges. The South Island made up a single region in the classification of Biggs et al. They suggested however, that some regions might warrant subdivision; the northern region might be divided into Northland, Waikato and Taranaki, and the South Island might be subdivided into Westland, Canterbury, Central Otago and the remainder. Division of their Northern ecoregion into "subregions" including the Coromandel, the Hauraki Plains, the Waikato and Mt. Taranaki is supported by my classification. Subdivision of the South Island into 12 distinct ecoregions is a major difference between the classifications, however, and is supported by much of my validation programme (see Chapters 3-5).

Rowe & Sheard (1981), Bailey (1983) and Omernik (1987) emphasized that ecoregion maps are products of hypotheses that must be tested, validated and improved. Chapters 3-5 of this thesis detail the results of water chemistry and stream fauna surveys within ten of the South Island ecoregions, undertaken to test the validity of my classification. They also provide some understanding of the relative importance of driving factors (Fig. 1.1) that affect the water chemistry and fauna of stream ecosystems.

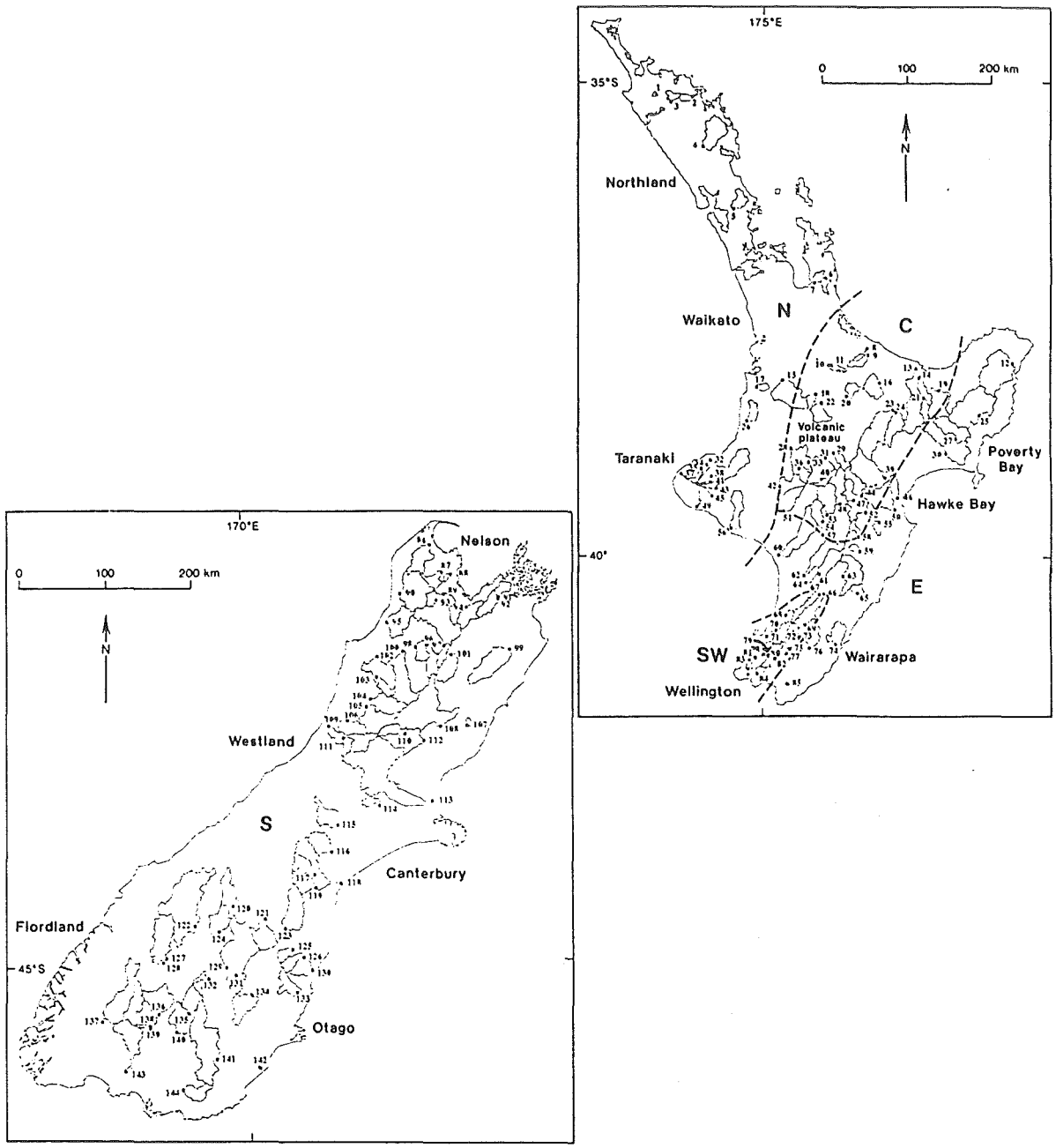


Figure 1.5 Map of New Zealand showing the main areas mentioned in the text and the five ecoregions proposed by Biggs et al. 1990 (from Biggs et al. 1990). Numerals indicate the catchments surveyed by Biggs et al.

Chapter 2

Climate and geomorphology of New Zealand ecoregions

A climatic and geomorphological history

The lotic ecoregions proposed in the previous chapter are based on the congruence of climatic and geomorphological factors. The characteristics that distinguish each region are the result of interactions that have occurred over millions of years. The soil profiles, geological formations and relief vary from region to region and were created by long term tectonic processes, contintental drift and global climatic conditions. Generally consistent overviews of New Zealand's geological, palaeoclimatic and floristic history are provided by Kemp (1978), Fleming (1962, 1975), Mildenhall (1980) and Stevens (1980).

Approximately 300 million years ago, the region which was to become New Zealand existed as a depression, the New Zealand Geosyncline, located off the eastern coast of the supercontinent of Gondwanaland (Stevens 1980). During the next 200 million years material eroded from Gondwanaland was deposited into this Geosyncline, accumulating layers of what would become sandstone and mudstone. An arc of volcanic islands, and subterranean volcanoes joined this formation. During the Rangitata Orogeny (c. 150-100 million yrs b.p.) the Geosyncline was uplifted by folding of the Earth's plates, and an ancestral New Zealand landmass emerged from the sea. This ancestral New Zealand extended from what is now known as New Caledonia to the vicinity of Campbell Island, and eastwards to the Chathams. At that time (100 million yrs b.p.) early New Zealand was probably occupied by biota from Gondwanaland, and the volcanic islands of the former Geosyncline. Early biota may have included terrestrial animals such as the tuatara, and ratite birds (Fleming 1979), as well as aquatic insects including certain groups of Gripopterygidae, Eustheniidae (Plecoptera), Chironomidae (Diptera), *Austrosimulium* (Diptera), Philorheithridae, and Helicophidae (Trichoptera) which are held in common by Australasia and Patagonia (Illies 1965, Brundin

1965, Ross 1967, Dumbleton 1972, Cowley 1978). The vegetation included ancestors of the podocarps, kauri, and early ferns (Newsome 1987). Between 100 and 80 million years ago, the process of geological uplift slowed, and erosional activity lowered relief across the "New Zealand" landmass. In the mid-Cretaceous (100 million yrs b.p.), angiosperms and the ancestors of the southern beeches became widespread across early New Zealand (Fleming 1962, Newsome 1987). During the following 20 million yrs (80-60 million yrs b.p.) the Gondwanaland supercontinent broke up, and the resulting fragments drifted apart. The start of the separation of New Zealand, New Caledonia, and New Guinea from Australia and Antarctica has been dated by seafloor spreading at 70-80 million years ago (Stevens 1980, McGlone 1985). Marine flooding since the Cretaceous (65 million years b.p.) peaked in the Oligocene (35 million years b.p.) and much of New Zealand was submerged (McGlone 1985). By the Eocene (55 million years b.p.), a wide sea gap had formed between Australia and New Zealand allowing strong westerly ocean currents and associated westerly winds to develop (Kemp 1978). Within 10 milion years of the formation of this gap (the Tasman Sea), New Zealand had lost its northern connection with New Caledonia (Stevens 1980).

The start of the Kaikoura Orogeny (13 million years b.p.) was the beginning of a period of extensive folding and faulting of the land, and resulted in the formation of new mountains, such as the Kaikoura Ranges, and the Southern Alps. Subsequently, a period of gradual climatic cooling resulted in the Pleistocene glaciations (beginning about 1.7-2 million yrs b.p.). These glaciations resulted in the loss of much forest vegetation from both islands, and were interdispersed with interglacial periods of rapid reforestation. The presence of *Nothofagus* forests (and by inference various other woody plant taxa) in the northwest and southwest South Island throughout the Otira Glaciation (80,000 - 20,000 years b.p.) has been deduced from the disjunct distribution of present day *Nothofagus* species, and fossil pollen records (Burrows 1965). McGlone (1988) suggested that destruction of South Island forests during these glacial periods may not have been caused by the severe decreases in annual temperatures *per se*, but rather by lower amounts of rainfall, and heavy frosts which severely restrict the distributions of forest tree species today. At the height of the last glacial

period (22,000-14,000 years b.p.), an almost continuous ice-cap stretched nearly 700 km along the Southern Alps, dividing the South Island in two (McGlone 1988). The snow and ice lines in both islands may have been 800-850 m below present levels, and mean annual temperatures are likely to have been about 4.5°C lower than at present (McGlone 1988). Dumbleton (1972) suggested that numerous aquatic invertebrates were almost certainly brought to extinction by these glacial advances. However, much of the aquatic fauna is assumed to have survived at lower altitudes and higher latitudes, and the persistence of numerous aquatic insect taxa in localised refugia such as north-west Nelson, the Marlborough Sounds, and Westland has been proposed by several authors (Craig 1969, Cowley 1978, Henderson 1985). Conversely, some elements of the flora and fauna may have exploited the greater area of land lying between the depressed treeline and the zone of perennial ice and snow (Newsome 1987).

The post-glacial period (14,000-10,000 yrs b.p.) was characterised by relatively rapid warming and increased precipitation. It was probably slightly warmer and wetter about 8,000 years ago than it is today (Denton & Karlen 1973, McGlone & Topping 1977). Reforestation was rapid, and substantially complete by c. 9500 years b.p., with Wellington and Central Otago probably among the last areas to be forested (McGlone 1988).

Volcanic eruptions during the last several million years changed the landscapes of Banks Peninsula, Taranaki, the volcanic plateau (central North Island), parts of the Coromandel, Auckland and Northland. These volcanic disturbances, particularly those in the central North Island may have contributed to evolutionary change within the New Zealand biota by destroying existing vegetation and landscapes, and by creating new habitats and potential biogeographical islands, such as Banks Peninsula. However, the arrival of humans about 800 years b.p. (Anderson 1989) provided a new catalyst for vegetational change. Early polynesians severely altered the natural vegetation by fire, and removed a significant proportion of the native browsing vertebrates (Newsome 1987, McGlone 1988, Anderson

1990). Prior to the arrival of Polynesians, 85-90% of New Zealand was forested, with conifer-broadleaf forests dominant (McGlone 1989). Matai (*Prumnopitys taxifolia*), totara (*Podocarpus totara*), and kahikatea (*Dacrycarpus dacrydiodes*) were probably the dominant podocarps along the east coast of both islands, whereas rimu (*Dacrydium cupressinum*) is likely to have dominated the wetter west coasts, and kauri (*Agathis australis*) was abundant from Northland to the Waikato (McGlone & Bathgate 1983, McGlone 1989, Brussell 1988). Following the arrival of polynesians, deforestation of lowlands by fire was widespread, particularly between 1200 and 1400 A.D., and most of the podocarp forests were eliminated from the eastern lowlands from northern Hawke's Bay to Southland (McGlone 1989). European settlers introduced new plants and animals, removed more forest, and introduced grazing mammals.

Today the relief and geology of New Zealand is continually being changed by the processes of uplift and erosion, and many human activities including farming, forestry, mining and continuing urbanisation are affecting the New Zealand landscape on a variety of scales.

South Island Ecoregions

The South Island was selected to test the validity of the ecoregion approach, because of its diversity in climate and geomorphology and its accessibility for study. Of the twelve lotic ecoregions proposed for the South Island, ten were surveyed during the summers of 1992-94. The two not considered were Marlborough (MP) and Nelson Plains (NF). The 10 ecoregions selected incorporated the widest range of climatic, geological and vegetation/land use conditions present on the island, and included several ecoregions with similar land use and vegetation, but different climatic conditions. Within each ecoregion, I intially identified 15-20 small headwater streams that were likely to have permanent flows. This was done using 1:50,000 topographical maps. Potential streams were widely distributed within each ecoregion. They were checked against the Land Resources Inventory (NWASCO 1975) to

ensure that each was in a catchment with the characteristic vegetation, geology and soil conditions of that ecoregion. Streams were then visited, and ten suitable streams, i.e. those with stony beds, widths less than 1 m, and riffles and runs present were sampled. These criteria were used in order to reduce the possibility of faunal microhabitat preferences biasing invertebrate abundances and assemblages. Sampling was not undertaken within three days of a storm event.

At each stream, a reach approximately 10 m long was selected (usually about 500 m-3 km from the source) and width, depth, and current velocity were measured at three points across the stream. A substrate index (Jowett & Richardson 1990) was calculated for three of the five 0.1m^2 quadrats subsequently sampled with a Surber sampler (Table 2.1). The substrate index measures the proportions of bed materials in six size classes, and ranges from 3 to 8 (3 being silty substrate and 8 entirely bedrock). Substrate categories and index calculation are shown in Table 2.2. Locations and full data on in-stream physical characteristics of each stream are given in Appendix 2.

In attempting to test the usefulness of my proposed ecoregions the physical in-stream characteristics of the streams sampled needed to be as uniform as possible. Therefore, despite large variations in climate, vegetation, geology and relief between regions, in-stream

Table 2.1 Mean values for the in-stream physical characteristics of the streams surveyed in 10 South Island ecoregions (x ±1 SE; n = 10 per ecoregion).

Ecoregion	Elevation (m)	Mean Depth (cm)	Mean Width (m)	Mean Velocity (m/s)	Mean Substrate Index	Total Pigment (μg cm^2)
WD	85 (23)	7 (0.5)	0.9 (0.2)	0.2 (0.02)	5.0 (0.1)	0.9 (0.2)
SE	114 (24)	6 (0.3)	0.6 (0.1)	0.2 (0.01)	5.0 (0.3)	1.4 (0.4)
NN	353 (92)	7 (0.9)	0.7 (0.1)	0.2 (0.01)	5.1 (0.1)	0.8 (0.3)
NE	301 (68)	9 (1.2)	1.1 (0.2)	0.2 (0.2)	5.4 (0.1)	2.4 (0.4)
PE	150 (36)	11 (1.0)	0.9 (0.1)	0.2 (0.01)	5.4 (0.1)	5.1 (1.3)
SA	1068 (85)	7 (0.9)	0.8 (0.1)	0.2 (0.01)	5.6 (0.1)	1.4 (0.5)
HC	687 (61)	11 (1.3)	1.3 (0.2)	0.3 (0.02)	5.2 (0.1)	4.7 (0.4)
EC	90 (33)	18 (2.3)	1.1 (0.2)	0.3 (0.04)	4.7 (0.1)	9.9 (2.1)
CO	436 (46)	14 (1.8)	1.1 (0.1)	0.3 (0.2)	4.6 (0.1)	4.7 (1.3)
SL	119 (32)	12 (1.5)	1.3 (0.1)	0.2 (0.02)	4.7 (0.2)	14 (3.9)

Table 2.2 Substrate size classes, and the substrate index values of Jowett & Richardson (1990). The method of index calculation is shown below the table.

Size classes	size range (mm)	index value
Bedrock	solid rock	0.08
Boulder	> 256	0.07
Cobble	64 - 256	0.06
Gravel	10 - 64	0.05
Fine gravel	2 - 10	0.04
Sand	0.06 - 2	0.03

Substrate index calculation = 0.08 (%bedrock) + 0.07 (%boulder) + 0.06 (%cobble) + 0.05 (%gravel) + 0.04 (%final gravel) + 0.03(%sand).

characteristics were similar. Nevertheless, streams in forested ecoregions (Westland, South-east Forest, North-west Nelson and North-east Nelson) were usually smaller (mean width and depth), had larger substrates, and less epilithic algal biomass than streams in pastoral catchments (East Coast Plains, Central Otago and Southland Plains)(Table 2.1). Very small streams were rarely found in pastoral ecoregions, because of high evaporation rates in exposed streams, the poor water retention of alluvial soils, and in some cases high demands for irrigation water.

WD Westland forest

The Westland forest ecoregion is a narrow lowland area (0-300 m a.s.l.) moulded by two main processes; movements of tectonic plates along the Alpine fault, and erosion and deposition associated with glaciers and rivers. The ecoregion runs the length of the West Coast of the South Island, from Cape Farewell to western Stewart Island. Its eastern boundary runs along the main Alpine Fault, including the coastal regions of Fiordland to the south, and the Tasman Mountains to the north (Fig. 2.1). Westland is a region of mild winter temperatures (monthly means 6.7-8.9°C); rainfall increases from north to south and east to west, with Westport in the north averaging 2200 mm and Milford Sound, in the south averaging 6300 mm (N.Z. Meteorological Service 1983). However, in the inland valleys of

Figure 2.1 Maps of the North and South Islands showing places discussed in the text.


Cape Farewell
Farewell Spit
GOLDEN BAY
Cape Stephens
D'URVILLE ISLAND
TASMAN BAY
French Pass
Motueka River
Tasman Ranges
Bryant Range
Richmond Range
Radiant Ranges
Matiri Ranges
Karamea R
KARAMEA BIGHT
Mt Owen 1875
Cape Foulwind
Paparoa Ranges
Mawheraiti
Mt Franklin 2339
Taramakau River
Hokitika
Greymouth
Puketeraki Range
Waiau River
Clarence River
Kaikoura Peninsula
Abut Head
Gillespies Beach
Paringa River
ALPINE FAULT
SOUTHERN ALPS
Mt Cook 3764
Mount Cook
Lake Tekapo
Haast River
Jackson Bay
Awarua Point
Mt Aspiring 3030
Lake Wanaka
Lake Hawea
Manuherikia River
Ida Burn
Milford Sound
Fiordland
George Sound
Lake Wakatipu
Mt Irene 1870
Lake Te Anau
SECRETARY I
Dagg Sound
Lake Manapouri
SOLUTION I
West Cape
CAMERON MTS
Puysegur Point
Te Waewae Bay
FOVEAUX STRAIT
Ruapuke I
Solander I
Codfish I
Muttonbird Islands
South Cape
North Trap
South Trap
STEWART ISLAND
Rangitata River
Ashburton River
CANTERBURY BIGHT
Waitaki River
Clutha River
Taieri River
Chaslands Mistake
PEGASUS BAY
Waimakariri River
Rakaia River
BANKS PENINSULA
CHRISTCHURCH
DUNEDIN
OTAGO PENINSULA
SOUTH ISL
Blenheim
WELLING
Kaikoura
Greymouth
Hokitika
Westport
Reefton
Murchison
Nelson
Motueka
Riwaka
Takaka
Collingwood
Karamea
Little Wanganui
Granity
Inangahua
Springs Junction
Lewis Pass
Hanmer Springs
Culverden
Waiau
Amberley
Rangiora
Kaiapoi
Oxford
Darfield
Sheffield
Lyttelton
Lincoln
Rolleston
Methven
Rakaia
Leeston
Ashburton
Tinwald
Hinds
Geraldine
Temuka
Timaru
Pareora
Waimate
Pukeuri
Damaru
Maheno
Hampden
Palmerston
Waikouaiti
Mosgiel
Brighton
Lawrence
Milton
Balclutha
Kaitangata
Gore
Mataura
Catlins
Owaka
Wyndham
Clinton
Waipahi
Tapanui
Riversdale
Lumsden
Mossburn
Manapouri
Te Anau
Kingston
Roxburgh
Middlemarch
Alexandra
Clyde
Cromwell
Arrowtown
Queenstown
Frankton
Glenorchy
Mt Earnslaw 2819
Wanaka
Tarras
Ranfurly
Dunrobin
Kurow
Otematata
Omarama
Twizel
Lake Ohau
Lake Pukaki
Lake Tekapo
Fairlie
Pleasant Point
Haast Pass
Makarora
Haast
Franz Josef Glacier
Whataroa
Hokitika
Kumara
Jacobs River
Kaniere
Otira
Arthurs Pass
Russell
Porters Pass
Springfield
Mt Arrowsmith 2795
Lake Coleridge
Mount Hutt
Methven
Rakaia
Leeston
Mt Somers
Tinwald
Ashburton
Hinds
Geraldine
Temuka
Timaru
Pareora
Waimate

Inangahua and Mawheraiti, in the rainshadow of the Paparoa Ranges, rainfall is lower (1600 -2400 mm) and winter frosts and fogs are frequent (Molloy 1988). The predominant vegetation is lowland podocarp-broadleaf forest including rimu (*Dacrydium cupressinum*), miro (*Prumnopitys ferruginea*), and totara (*Podocarpus totara*), with an understorey of *Coprosma* and numerous ferns. Large patches of unimproved pasture, mixed indigenous scrub (*Leptospermum*), and exotic forest (mainly *Pinus* spp.) occur near urban areas, whereas pakihi vegetation consisting of umbrella fern (*Gleichenia microphylla*), wirerush (*Empodisma minus*), rushes and sedges (*Baumea* and *Juncus* spp.) occurs on remnant river terraces (Newsome 1987). Beech forest (*Nothofagus* spp.) is absent for 180 km between Taramakau and the Paringa Rivers (Burrows 1965, Molloy 1988). Westland is geologically complex with large areas of post-glacial alluvium, and outcrops of greywacke, phyllite, schist, and limestone. The far north of the Tasman Mountains is mainly granite and granodiorite (NZ Geological Survey 1972b). Recent alluvial soils are common along major river floodplains, and strongly podsolised soils are spread throughout the region (Raeside et al. 1968). Nutrients are rapidly leached out of these podsolised soils by rainfall; groundwater pH is usually low, carbon/nitrogen ratios are often high, and nutrient availability is limited (Molloy 1988).

Streams sampled in this ecoregion were small, with brown waters, and cobble and pebble beds. Bryophyte communities were often associated with compacted cobble substrates, logs and debris dams in these streams. Stream bed slope was generally low (<3°), and few signs of bank undercuttiing were evident despite the high rainfall of the region. The podocarp forest canopy greatly reduced light levels in these streams, and an understorey of tree ferns and hanging epiphytes commonly occurs over them (Fig. 2.2).

NN North-west Nelson forest

North-west Nelson forest ecoregion is a highland area (300-1800 m a.s.l.) north of Greymouth encompassing the Paparoa, Radiant, and Matiri Ranges, and the Tasman Moun-

a)

b)

Figure 2.2 Westland Forest (WD) ecoregion streams were small brownwaters with cobble and pebble beds in mixed podocarp-broadleaf rainforest, a) Lake Kaniere tributary (WD1), b) a south westland stream (WD7).

tains (Fig. 2.1). This region receives some of the highest rainfall in the South Island, particularly in the west where rainfall normals range from 2400-9600 mm (NZ Meteorological Service 1985). Winters are cool (monthly means 3.1-4°C), and summers warm (11.7-13.8°C)(NZ Meteorological Service 1983). The region is heavily forested in beech (*Nothofagus*), dispersed with mixed lowland/highland podocarp-broadleaf forests consisting of rimu, kamahi (*Weinmannia racemosa*), tawa (*Beilschmiedia tarairi*), Hall's totara (*Podocarpus cunninghamii*) and assorted broadleaf species. Higher elevations (above 1200 m) are primarily tussock, and sub-alpine scrub. The geology of this ecoregion is complex, as a series of major faultlines dissect the four major mountain ranges. These mountain ranges were formed on Tertiary sandstones, mudstones and limestones, Palaeozoic granites and gneiss, and Precambrian greywackes (Taylor & Pohlen 1968). Consequently, the soils also vary although gleyed podsols predominate; yellow brown calcareous subsoils are associated with karst formations in the Paparoas (Molloy 1988).

North-west Nelson streams had brown-waters, with surface foam present at several sites. Bryophyte-covered cobbles often dominated the beds, and mixed *Nothofagus*-podocarp canopies shaded the stream channels. Broadleaf species and ferns were common along stream banks. Streambed slopes were generally steeper than in Westland streams (approximately 3-5°) and several streams consisted of rapid/pool cascades. Few streams had visible bank undercutting (Fig. 2.3).

NE North-east Nelson forest

North-east Nelson forest is a mountainous ecoregion bordering the flood plains of the Motueka and Waimea Rivers to the east and the Wairau River to the west (Fig. 2.1). Rising from sea level to an altitude of 1800 m it incorporates the Bryant and Richmond Ranges, and the Marlborough Sounds. Summers are very warm with occasional daily temperatures above 30°C, and dry north westerly foehn winds. Annual rainfall in the west is approximately 1000-2000 mm, with rainfall normals over a 30 yr period slightly higher at

a)

b)

Figure 2.3 North-west Nelson (NN) streams were typically brownwaters, and several had surface foam present, a) Fossil Creek tributary, near the Heaphy Track (NN1), b) small creek in the Buller River catchment (NN3).

1200-4800 mm in the ranges. Mixed beech (*Nothofagus* spp.) and lowland podocarp forest (rimu, miro, totara and kamahi) occur throughout the ranges, although exotic forest plantations (*Pinus* spp.) have increased in numbers in recent years. In the Marlborough Sounds, mixed indigenous scrub dominated by *Leptospermum* is common, whereas improved pastures have been developed on the northern valley floors (e.g. Rai Valley). A series of major faultlines dissect the region and bands of different bedrock geology occur across the ecoregion. Greywacke, and argillite formations dominate the Richmond Range, whereas schist is common along the Wairau River (NZ Geological Survey 1972b). Podsol soils occur in the Richmond Range, with yellow-brown earths east of Mt. Riley (Raeside et al. 1968).

The streams in this ecoregion had beds dominated by bryophyte-covered boulders and cobbles. The mixed *Nothofagus*-podocarp canopy was more open than in Westland forests, although ferns, broadleaf shrubs and flax (*Phormium* spp.) were common in riparian zones. Stream beds were generally steeper than in North-west Nelson (approximately 5°), and rapids, pools and cascades were common. Stream banks were often undercut (Fig. 2.4).

SA - Southern Alps

The Southern Alps ecoregion is a mountainous zone stretching from Fiordland in the south to Lewis Pass in the north. Its eastern boundary lies alongside the Westland forest ecoregion, and its western boundary is at approximately 1000 m a.s.l. and in line with the headwaters of the glacial lakes Te Anau, Wanaka, Hawea, Ohau, Pukaki, Tekapo, Coleridge, Lyndon and Sumner (Fig. 2.1). The landscape of this ecoregion has been sculptured by folding, faulting, and erosion particularly by the glaciers and ice caps of the Quaternary period (Stevens 1980). The Southern Alps ecoregion incorporates two climatic and topographic zones, the wet western slopes, and the drier eastern slopes. The western slopes have higher average rainfall (5000-11000 mm p.a.) than the eastern slopes (1500-5000 mm p.a.) (Molloy 1988). The high rainfall on the western slopes causes accelerated erosion rates, but also rapid revegetation, since the high rate of weathering increases the availability

a)

b)

Figure 2.4 North-east Nelson (NE) streams, a) Ronga Saddle stream near the Rai Valley (NE7), b) a small stream in the Okiwi Valley (NE8).

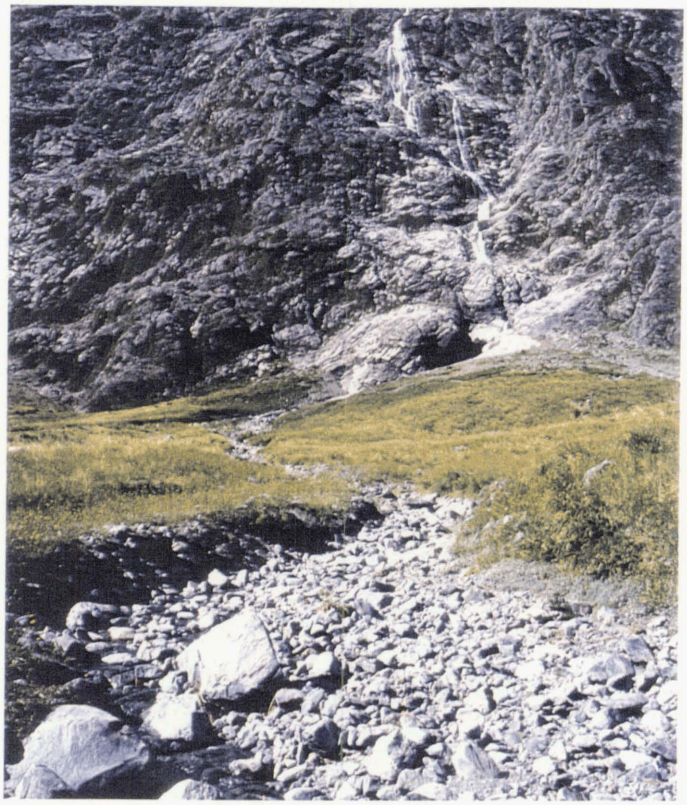
of plant nutrients (Molloy 1988). As a result, podocarp-hardwood forests (such as rimu, miro, and matai) are common on valley sides in the west. In contrast, the eastern slopes with lower rainfall have more stable soils and support *Nothofagus* forests. These eastern forests are older and have nutrient-depauperate soils. Above about 1000 m snow tussock (*Chionochloa* spp.) dominates, and is replaced at higher elevations (1600 m a.s.l.) by sub-alpine scrub and herbfields that include alpine daisies, buttercups, gentians (*Gentiana* spp.) and spaniards (*Aciphylla* spp.), and finally, snow and exposed rock. Bands of greywacke, quartzo-feldspathic schist, and gneiss extend through most of the Alps, although the Fiordland region is dominated by paragneiss and amphibolite (NZ Geological Survey 1972b). The region is characterised by high rainfall throughout the year; snow falls predominantly in winter but can occur in any season (NZ Meteorological Service 1985). The main soils are earths, and at higher elevations only bare rocks and scree are found.

Southern Alps streams were amongst the steepest sampled in this survey (>5°). Streambeds were dominated by loose boulders and large cobbles devoid of bryophytes, and were either continuous riffles or riffle/pool cascades. Alpine vegetation was limited to the banks and did not provide instream cover. Little sign of bank undercutting was evident, and high flows were probably contained within stream channels for the most part (Fig. 2.5).

HC – High country

The High country ecoregion consists of rolling hill country and foothills east of the Southern Alps and west of the Canterbury and Southland Plains (Fig. 2.1). Elevation within the ecoregion ranges from 300-2000 m a.s.l. Summers are often hot and dry with warm north westerly foehn winds bringing temperatures above 30°C. In winter, snow may lie on the ground for weeks. Rainfall normals are between 600-2400 mm p.a. Snow tussock (*Chionochloa* spp.) is the predominant vegetation, although pockets of indigenous scrub (*Dracophyllum*, *Hebe*, *Podocarpus nivalis*, *Phyllocladus alpinus* and *Discaria toumatou*) are common (Newsome 1987). Several extensive *Nothofagus* forests also occur along the

a)



b)

Figure 2.5 Southern Alps (SA) streams had clear waters streams and little or no riparian cover, a) Lake Marion inflow stream (SA7), b) a small tributary, in the foreground, flowing into the Tasman Valley (SA9).

Dampier, Poulter and Puketeraki Ranges. The landscape is depositional, and consists mostly of glacial or alluvial material including fans, glacial outwash plains, alluvial terraces and moraines with associated yellow-brown and yellow-grey earths (Raeside et al. 1968, Molloy 1988). Soil pH and nutrient concentrations are higher than in the Alps because Haldon and Hurunui steepland soils are only weakly leached (Molloy 1988). Greywacke and argillite are the main geological formations in the north, and schist occurs throughout Otago in the south (New Zealand Geological Survey 1972b).

The High Country streams were primarily in open tussock or scrub covered catchments, and had boulder and cobble dominated beds. Bryophytes were absent, however, epilithic algal blooms were observed occasionally in streams. Streambed slopes were low (about 3°), and riffles and runs were common. Riparian vegetation consisted of tussock and introduced plants including broom (*Cytisus scoparius*), gorse (*Ulex europaeus*), and assorted grasses, none of which provided much shading of the streambeds (Fig. 2.6). Stream bank undercutting was rare, however stock, particularly sheep, were often seen in the streambeds.

EC - East Coast Plains ecoregion

The East Coast Plains is a lowland area (0-300 m a.s.l.) stretching from the Waiau River in the north to the city of Oamaru in the south (Fig. 2.1). The plains were produced by successive glaciations which eroded material from the Southern Alps, material which subsequently built up from a series of four gently sloping fans produced by the Waimakariri, Rakaia, Ashburton, and Rangitata Rivers. The resulting soils are post glacial alluvium and loess (Molloy 1988). The ecoregion is characterised by low annual rainfall (400-1200 mm), warm summers (monthly means 15.2-17°C) with occasional hot foehn north westerlies, and cool winters (5.1-6.9°) with frequent frosts and occasional snow (NZ Meteorological Service 1985). The region is intensively farmed, and improved grasses are the dominant vegetation. They include perennial and short rotation ryegrasses (*Lolium* spp.), white clover (*Trifolium repens*), red clover (*T. pratense*), cocksfoot (*Dactylis glomerata*), timothy

a)

b)

Figure 2.6 High Country (HC) streams a) Dry Stream near Porters Pass (HC6), b) Bullocky Stream, Burkes Pass (HC7).

(*Phleum pratense*), yorkshire fog (*Holcus lanatus*) and lucerne (*Medicago sativa*). Urban development is also prevalent, with several cities and major towns including Christchurch, Timaru, Oamaru, and Ashburton occurring in the region.

Streams sampled in the East Coast Plains ecoregion were of three types; natural, drains, and water races. "Natural'' streams were the least modified, and usually occurred along the rural-urban boundary, whereas ''drains'' were natural streams that had been straightened and channelised. Drains had high banks (1-2 m high) as a result of excavation by ditch diggers. The third stream type comprised of irrigation water races which were entirely man-made, typically had faster flows than natural streams and drains, and were relatively uniform in depth. The banks of all streams were covered in grasses, and adjacent hedges often prevented livestock having access to the streams. Watercress and grasses were abundant in most streams, and often severely reduced light availability to the streambed. Beds dominated by pebbles and cobbles lacked bryophytes, but were often supported 'thick' epilithic communities (Fig. 2.7).

PE - Banks Peninsula

Banks Peninsula consists of two deeply eroded basaltic and andesitic volcanic calderas formed during the Tertiary period (Stevens 1980)(Fig. 2.1). The Peninsula has a climate similar to the East Coast ecoregion with very warm summers and moderately warm winters. A pronounced rainfall gradient occurs with the north-eastern slopes in rainshadow, and the central region averaging 1200-2400 mm p.a. Much of the Peninsula is covered in grassland/tussock (*Poa* and *Festuca* spp.) and mixed indigenous scrub including bracken (*Pteridium esculentum*), mahoe (*Melicytus ramiflorus*), fuchsia (*Fuchsia excorticata*), wineberry (*Aristotelia serrata*), and species of *Coprosma*, and *Hebe* (Newsome 1987). The original loess soils on the drier slopes have been transformed over time into dense grey soils, whereas in the wetter regions brown volcanic loamy clays have formed (Molloy 1988).

The Banks Peninsula streams were in mixed tussock/forest catchments. They had

a)

b)

Figure 2.7 East Coast Plains (EC) ecoregion streams were modified to different degrees, a) Wildon drain, near Springston (EC1), b) Lakeside drain, near Lake Ellesmere (EC4).

partially shaded beds dominated by boulders and cobbles, which were frequently colonised by bryophytes and algae. Most streams consisted of riffles, pools and cascades, and had slopes of 3-5°. Pronounced undercutting of banks (up to 1m) occurred in several streams. Stream waters were often cloudy, apparently as a result of livestock disturbance (Fig. 2.8).

CO - Central Otago basin

Central Otago basin ecoregion includes the valleys of the upper Taieri, Ida Burn and Manuherikia Rivers (Fig. 2.1). Central Otago is a distinctive lowland region (0-300 m a.s.l.) of improved pasture with a relatively severe semi-arid climate. It has the lowest rainfall in the South Island (350-500 mm p.a.), very hot summers (daily means 25-35°), cold winters (monthly means -1-1.4°), and frosts may occur on 30-50% of the days of the year (NZ Meteorological Service 1985). Geologically, the ecoregion is reasonably uniform, consisting of aggraded glacial and alluvial schist gravels, along with semi-arid brown-grey and yellow-brown earths (Raeside et al. 1968). Calcium, magnesium, and potassium concentrations may be comparatively high in these soils, but nitrogen concentrations are usually low Molloy 1988).

The Central Otago streams were in tussock or improved grassland catchments, and had loose cobble, gravel and silty beds. Riffles and runs predominated and slopes were <3°. Bryophytes were rarely seen, although algal blooms were prolific at some sites. Most streams were gently sloping, with meandering channels. Depositional bars and bank under-cutting were common on bends. Riverbank grasses readily covered streambeds but did not occur extensively as in East Coast Plains streams. Pastoral sheep farming is the primary land use activity in this region (approximately 2 million sheep occur in Central Otago, Molloy 1988), and not surprisingly, sheep were frequently observed in streambeds (Fig. 2.9).

a)

b)

Figure 2.8 Banks Peninsula (PE) streams were in semi-forested catchments, a) Little River tributary stream (PE2), b) Grehan Creek, near Akaroa (PE7).

a)

b)

Figure 2.9 Central Otago (CO) streams, a) Spain Creek (CO4), b) Ida Burn (CO7).

SL - Southland Plains

The Southland plains ecoregion includes the flood plains of the Aparima, Oreti, Mataura, lower Clutha and Taieri Rivers, and the Waimea Plains (Fig. 2.1). The Southland Plains like the East Coast plains is an area of intensive mixed farming, and the principal vegetation cover is improved pasture. Along the east coast between Milton and Dunedin, tussock grassland (*Poa* and *Festuca* spp.) and scrub, especially gorse (*Ulex europaeus*), occur along with numerous exotic forests (*Pinus* spp.). Warm summers (mean monthly 13-15°) and cool winters (4.6-6.5°) are characteristic of this ecoregion, which has moderate rainfall, 1000-1200 mm, evenly distributed throughout the year (NZ Meteorological Service 1985). Aggraded glacial and alluvial gravels and loess associated with dense grey soils occur in drier areas (700-900 mm p.a.), whereas lowland brown earths with pockets of organic and gley soils are widespread in regions of higher rainfall (>900 mm p.a.) (Molloy 1988).

The ten streams sampled in this ecoregion were in intensively farmed catchments and had beds dominated by loose cobbles and gravels. Stream channels were similar to those in the East Coast Plains with high banks (>1 m) often eroded by livestock, and grasses and watercress invading the streambeds. Streams were gently sloping (1-3°) with riffles and runs, and were usually bank-full (Fig. 2.10).

SE - South-eastern Forest

The South-eastern Forest ecoregion consists of two geographical areas; Catlins State Forest, and eastern Stewart Island (Fig. 2.1). Both consist of rolling hill country (0-800 m a.s.l.) with mixed-podocarp forest vegetation. Much of the forest canopy is dominated by rimu (*Dacrydium cupressinum*), kamahi (*Weinmannia racemosa*), miro (*Prumnopitys ferrugineus*), rata (*Metrosideros umbellata*) and quintinia (*Quintinia acutifolia*). In the Catlins, limited pockets of exotic forest (*Pinus* spp.), and scrub consisting of *Coprosma*, *Pittosporum* and five finger (*Pseudopanax arboreus*), tree and ground ferns, occur (Wilson 1982, Newsome 1987). Summers are usually warm (12.9-13.4°) and winters are cool (5.5-

a)

b)

Figure 2.10 Southland Plains (SL) streams, a) Ryal Bush drain (SL1), b) Roy Stream (SL4).

6.7°); rainfall is plentiful and evenly distributed throughout the year (1200-2400 mm p.a.). Strong coastal winds deposit seaspray in the freshwater systems and elevate sodium chloride levels (Chadderton 1988). Catlins has primarily sandstone and siltstone bedrock, whereas Stewart Island is formed from granite, grandiorite, and diorite (NZ Geological Survey 1972). Soils range from brown earths to podsols and organic soils.

South-east Forest streams were small, shallow and gently sloping, with brownwaters. Their cobble and pebble beds were frequently covered in bryophytes, and were heavily shaded by canopy and understorey layers including ferns, and epiphytes. Small riffles and sandy/mud pools were common, and the streambed and 'flood channel' were usually poorly defined with little obvious bank undercutting (Fig. 2.11).

a)

b)

Figure 2.11 South-east Forest (SE) streams, a) Fern Gully stream, Stewart Island (SE2), b) Horseshoe Bay stream, Stewart Island (SE3).

Chapter 3

Benthic invertebrate assemblages: regional patterns

Introduction

Any attempt to associate the distributions of aquatic invertebrates with regional macro-environmental conditions is complicated by past biogeographical conditions which may preclude the presence of taxa from a region. Paleogeographical events such as climatic changes, alterations in sea levels, emergence and subduction of landmasses and volcanic activity may result in localised extinctions, or conversely, the creation of areas of isolated endemism. Evidence confirming the influence that paleogeographical events have had on the distribution of present day taxa is often difficult to obtain. However, Northern Hemisphere stream invertebrate communities have been shown to vary between biogeographic regions in taxonomic richness, community composition and functional feeding groups (Ross 1963, Minshall et al. 1983, 1985, Corkum 1989). Over long periods of time, evolutionary changes are likely to be influenced by macro-environmental conditions, such as climatic and geological events, even at a regional scale. Hence the relationships between stream invertebrate communities and their catchments have received increasing attention (Ross 1963, Hynes 1975, Molles 1982, Minshall et al. 1983, 1985, Corkum 1989). Ross (1963, 1967) noted a strong correspondence between the distribution of trichopterans and climatic and vegetation biomes in North America, and suggested that the physical properties of a region's climate and vegetation impose a special set of ecological conditions on stream fauna. Similarily, Corkum (1989) proposed that vegetation, geology and land use influenced macroinvertebrate community structure in northwestern North American streams. Likewise, Whittier et al. (1988) found differences in the macroinvertebrate faunas of streams of eight Oregon ecoregions, which had been classified by differences in soil, potential natural vegetation and land use. Minshall et al. (1983) concluded that changes in organic matter standing

stocks, rates of primary production, and invertebrate functional feeding groups were effected at the catchment level by climate, geology and the nature of the riparian vegetation.

Previous New Zealand studies have indicated some regional variability occurs in the distributions and diversity of several major taxa, particularly the Ephemeroptera which are most diverse in the north of the North Island (Summerhayes 1983, Towns 1983, Collier 1993). In contrast, the Plecoptera are best represented in Westland and north-west Nelson (Cowie 1980, Collier & Winterbourn 1987, McLellan 1991), some trichopteran taxa are restricted to north-west Nelson, Westland and the alpine regions of the South Island (Cowley 1978, Fleming 1979, Henderson 1983, Collier 1993), some Blephariceridae occur only in Southland and on Banks Peninsula (Craig 1969), and several species of Simuliidae have been found only in parts of Westland, Southland, mid-Canterbury, and the northern South Island (Dumbleton 1973).

Biggs et al. (1990) suggested that the primary factors influencing the abundance and composition of invertebrate assemblages in New Zealand rivers are climatic conditions including temperature and precipitation, catchment geology, vegetation and land use, and relief. The importance of climatic extremes in New Zealand, including temperature, storm magnitude and storm frequency were emphasised by Cowie (1980) and Winterbourn et al. (1981) who suggested that the unstable nature of New Zealand's stream systems may be responsible for the ecological flexibility of many of our benthic invertebrates. The influence of catchment development on taxonomic richness, abundance and composition of stream communities is clear from the work of Quinn & Hickey (1990) who surveyed 88 rivers nationwide.

The fundamental assumption underpinning my study is that the composition of New Zealand invertebrate assemblages is determined primarily by climate, vegetation, geology and catchment land use. If this is so, regions characterised by widely varying macro-environmental conditions should have structurally dissimilar aquatic communities.

My primary aim therefore, was to characterise the macroinvertebrate faunas of the 100 headwater streams described in Chapter 2 (Appendix 2), and to evaluate how well the

stream faunas within each ecoregion corresponded to my lotic ecoregion classification (described in Chapter 1). In other words, I wanted to know whether "characteristic" benthic faunal assemblages occurred within headwater streams in each ecoregion.

Materials and methods

Benthic samples were collected from 100 small headwater streams (described in Chapter 2) during the summers of 1993-1994. At each site, a reach approximately 10 m long was selected and 5 Surber samples (0.11 m^2, 0.25 mm mesh) were collected. All samples were taken from rapids and runs within the sampling reach. Samples were preserved in the field in 10% formalin, and sorted in the laboratory under 10X magnification.

Identifications were made from descriptions published by McFarlane (1951), Winterbourn (1972), Chapman & Lewis (1976), McLellan (1977), Cowley (1978), Winterbourn & Gregson (1989), Death (1990) and McFarlane (1990). Oligochaetes and chironomid head capsules were mounted on microscope slides in lactophenol-pva and identified using the keys of Brinkhurst (1971) (oligochaetes), Stark (1989), and Boothroyd (1989) (chironomids).

Subsequently, taxa were assigned to functional feeding groups as described by Cummins (1973) and modified by Cowie (1980). Membership of functional feeding groups was determined from Cowie (1980), Rounick et al. (1982), Winterbourn et al. (1984), and Chadderton (1988). Several species span functional feeding groups, e.g. facultative shredders/collector-browsers *Austroperla cyrene* and *Olinga feredayi*, and filter-feeders/grazers *Aoteapsyche* spp. Nevertheless, most species could be allocated to a single functional feeding group.

Statistical analysis

Benthic stream communities in each ecoregion were characterised in terms of abundance, taxonomic richness and functional feeding group structure, and compared between

ecoregions using these criteria. Sets of mean values for the 10 streams in each ecoregion were tested for normality and homoscedasticity, and results with unequal variances were log transformed and analysed with ANOVA. Following a significant ANOVA ($P < 0.05$) comparisons of means were made with a Tukey HSD test at the 0.05 level of significance (STATISTIX 3.5; Analytical Software 1991). Data that could not be transformed successfully were analysed statistically using the non-parametric Kruskal-Wallis test (Sokal & Rohlf 1981). Where differences are stated to be significant in the text a probability level of $P < 0.05$ or better is inferred.

Community data for the 100 streams were analysed by multivariate techniques in order to assess the validity of my ecoregion classification. Multivariate analyses included two-way indicator species analysis (TWINSPAN; Hill 1979a) and detrended correspondence analysis (DECORANA; Hill 1979b), both calculated using the PC-ORD software package (McCune 1991). TWINSPAN is a method of hierarchical analysis that classifies both streams and species into groups of similar composition, and identifies "indicator species" that are diagnostic of each division. Classification was performed on presence/absence data as this was considered more informative in distinguishing between differences in the assemblage structure of communities than quantitative data which were also used in preliminary analyses. Detrended correspondence analysis was used to arrange streams and benthic communities in an objective order along three axes. The strengths of axes are measured as eigenvalues and the relative importance of an axis in explaining the variation of a data set can be expressed as the eigenvalue divided by the sum of the eigenvalues of the three axes calculated by this software (Weatherley & Omerod 1987). DECORANA was performed using presence/absence data on the entire data set, and an analysis using quantitative data was performed on a subset of Central Otago, Southland and East Coast Plains streams which could not be separated by TWINSPAN or DECORANA using presence/absence data.

Results

Taxonomic diversity

Westland had the highest number of taxa (96) collected from an ecoregion, and was especially rich in plecopteran, coleopteran, dipteran and trichopteran taxa (Table 3.1). North-east Nelson had the second highest number of taxa (80), including the most ephemeropteran taxa collected in any region (9). This high richness of mayfly taxa occurred primarily because a tributary of Six mile Creek (NE9), near Lake Rotoiti, had seven species present. The fewest macroinvertebrate species were recorded in the Southern Alps (39), Southland Plains (40), Central Otago (45) and East Coast Plains (49). The Southern Alps ecoregion had representatives of most taxonomic groups, whereas the three pastoral ecoregions (CO, SL, and EC) were poorly represented by ephemeropteran, plecopteran, and coleopteran taxa (Table 3.1). In contrast, the pastoral ecoregions had the highest numbers of molluscan taxa (4,6, and 4, respectively). A complete quantitative list of taxa is given in Appendix 3.

The mean number of taxa collected from each stream in each region was significantly greater in the forested and scrub-covered ecoregions than in the pastoral and alpine ecoregions. North-east Nelson, the High Country and Westland had the highest mean number of taxa per stream, and along with North-west Nelson and Banks Peninsula their numbers were significantly higher than those in Central Otago, Southland Plains and the Southern Alps (Fig. 3.1, Table 3.2).

Table 3.1 Total number of macroinvertebrate taxa collected from all 10 streams in each ecoregion.

	WD	SE	NN	NE	PE	HC	CO	SL	EC	SA
Ephemeroptera	7	5	7	9	5	5	1	1	1	2
Plecoptera	16	9	13	13	7	11	2	1	0	8
Megaloptera	1	0	1	1	1	1	1	1	0	0
Coleoptera	6	3	4	4	3	2	1	1	2	2
Diptera	25	16	16	20	18	21	13	12	18	12
Trichoptera	30	11	26	22	15	19	11	9	11	9
Mollusca	3	1	1	2	2	3	6	4	4	1
Other	8	10	7	9	13	9	10	11	14	5
Total	96	55	75	80	62	71	45	40	49	39

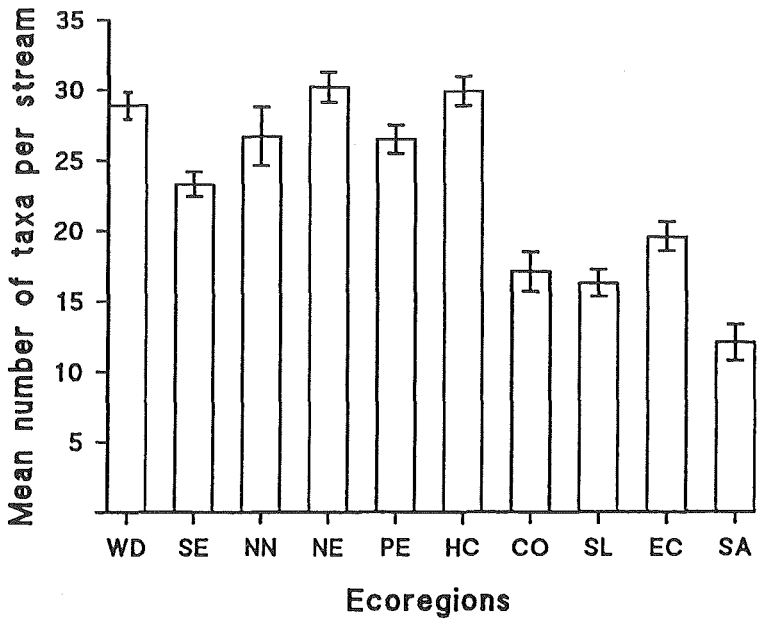


Figure 3.1 Mean number of invertebrate taxa collected in each ecoregion (±1SE; n=10).

Table 3.2. Statistically significant differences between ecoregions in the mean numbers of taxa within each taxonomic order, mean invertebrate densities, and mean numbers of total taxa (n = 10). *F* and *P* values ANOVAs; highest and lowest ecoregion groups were identified by Tukey HSD tests ($P < 0.05$).

Order	Highest	Lowest	$F_{[9,99]}$	*P*
Ephemeroptera	NE, NN, WD, PE	CO, SL, EC, SA	32.85	<0.01
Plecoptera	NE, NN, WD, SE	CO, SL, EC	35.60	<0.01
Megaloptera	HC, PE	-	10.39	<0.01
Coleoptera	NE, NN	SL, EC, SA, PE	3.51	<0.01
Diptera	HC	SL, SA	6.47	<0.01
Trichoptera	HC	SA	13.9	<0.01
Others	CO, SL, EC	SA	11.12	<0.01
Invertebrate densities	SL	SA, NN	15.16	<0.01
Mean no. of taxa	NE, NN, WD, PE HC	CO, SL, SA	27.04	<0.01

Further analysis of taxonomic orders confirmed that insect taxa were always well represented in the streams of forested ecoregions, whereas "Other" taxonomic groups, including Mollusca, Oligochaeta, and Platyhelminthes were more abundant in ecoregions with open-canopied streams. Significant differences in numbers of ephemeropteran taxa were

found between North-east and North-west Nelson, Westland, and Banks Peninsula, all of which had greater mayfly species richness than Central Otago, Southland, East Coast Plains and the Southern Alps (Fig. 3.2, Table 3.2). Similarly, the numbers of plecopteran taxa were significantly higher in ecoregions with forested streams (NE, NN, WD and SE) than in those with non-forested streams (CO, SL, EC). The megalopteran *Archichauliodes diversus*

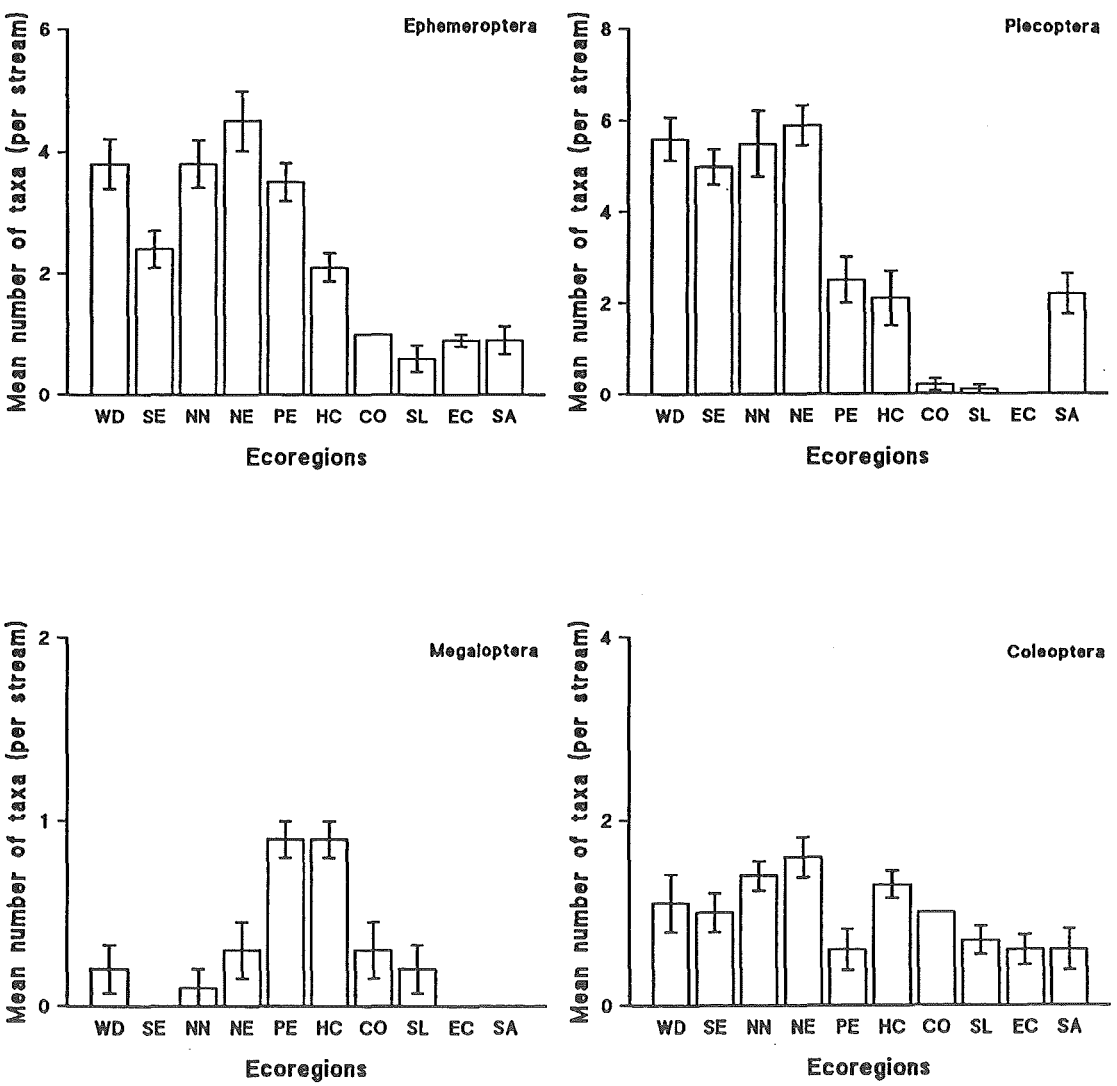


Figure 3.2 Mean number of taxa per order in streams in each ecoregion (±1SE; n=10).

(Corydalidae) was often collected in High Country and Banks Peninsula streams, but was less frequently found in other ecoregions. Furthermore, numbers of coleopteran taxa were high in the two Nelson ecoregions but low in the Southland and East Coast Plains, Banks Peninsula and the Southern Alps (Fig. 3.2, Table 3.2). The High Country ecoregion recorded the greatest number of dipteran taxa per stream (4-10), significantly higher than in Southland and the Southern Alps where 2-7 and 1-6 dipteran taxa were found per stream, respectively (Fig. 3.3). Trichopteran taxonomic richness was highest in High Country streams, and lowest in the Southern Alps (Fig. 3.3, Table 3.2). The "Other" taxonomic category was most prolific in the three pastoral ecoregions; Central Otago, Southland and the East Coast Plains, and was poorly represented in the Southern Alps region (Fig. 3.3).

Invertebrate densities were highest in the Southland Plains (2500-24100 m^{-2}), and lowest in the Southern Alps (65-2100 m^{-2}) and North-west Nelson (210-1170 m^{-2})(Fig. 3.4, Table 3.2).

Functional feeding groups

The trends observed in the distribution of invertebrate groups between forested and pastoral ecoregions were not as clear when functional feeding groups were considered. The collector-browsers was the commonest feeding group, including 61-92% of the fauna in all ecoregions (Fig. 3.5). Collector-browser ephemeropterans were usually the most abundant members of this functional feeding group, however they were more poorly represented in the three pastoral ecoregions, Central Otago, Southland and East Coast Plains than in other ecoregions (Fig. 3.6). Collector-browsing Crustacea were abundant in the South-east Forest, but were poorly represented elsewhere (Fig. 3.6).

Filter-feeders were poorly represented in all ecoregions except Banks Peninsula and North-east Nelson where they accounted for 30% and 24% of the fauna, respectively (Fig. 3.5).

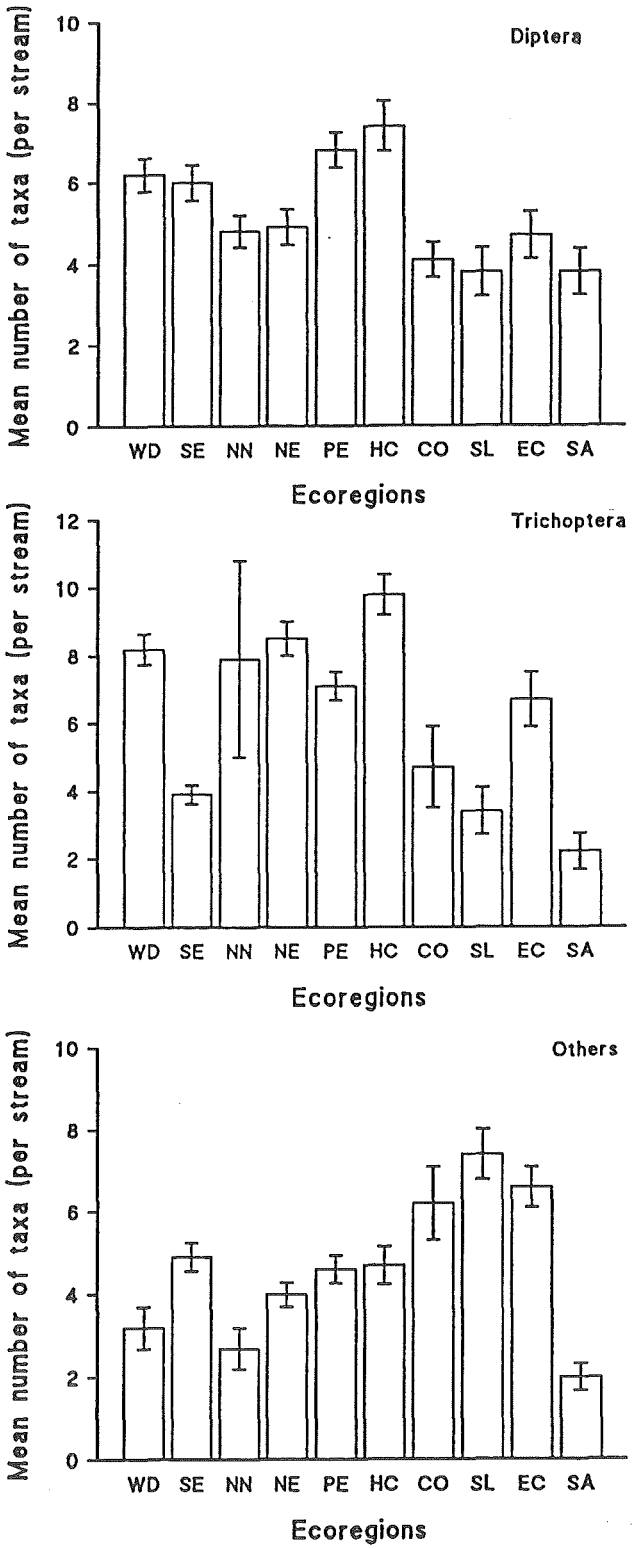


Figure 3.3 Mean number of taxa per order in streams in each ecoregion (±1SE; n=10).

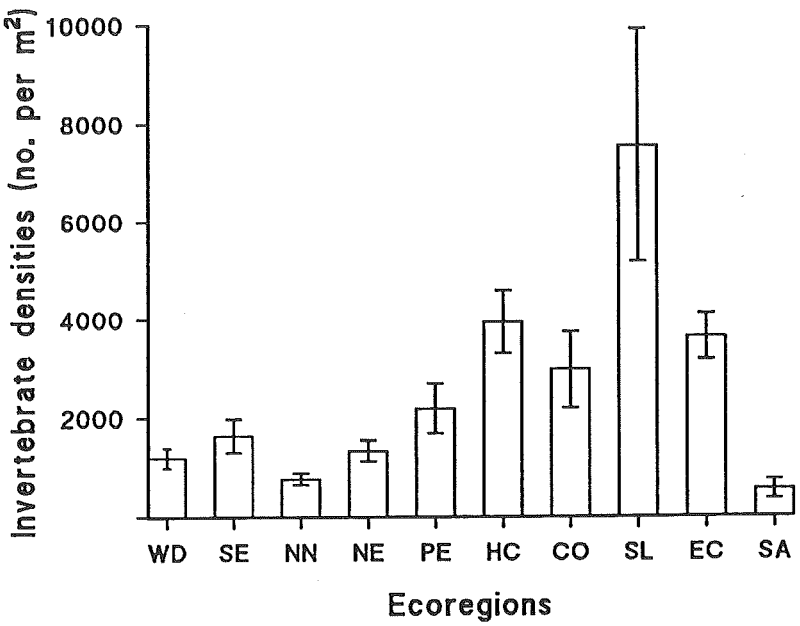


Figure 3.4 Mean invertebrate densities in streams in each ecoregion (±1SE; n=10).

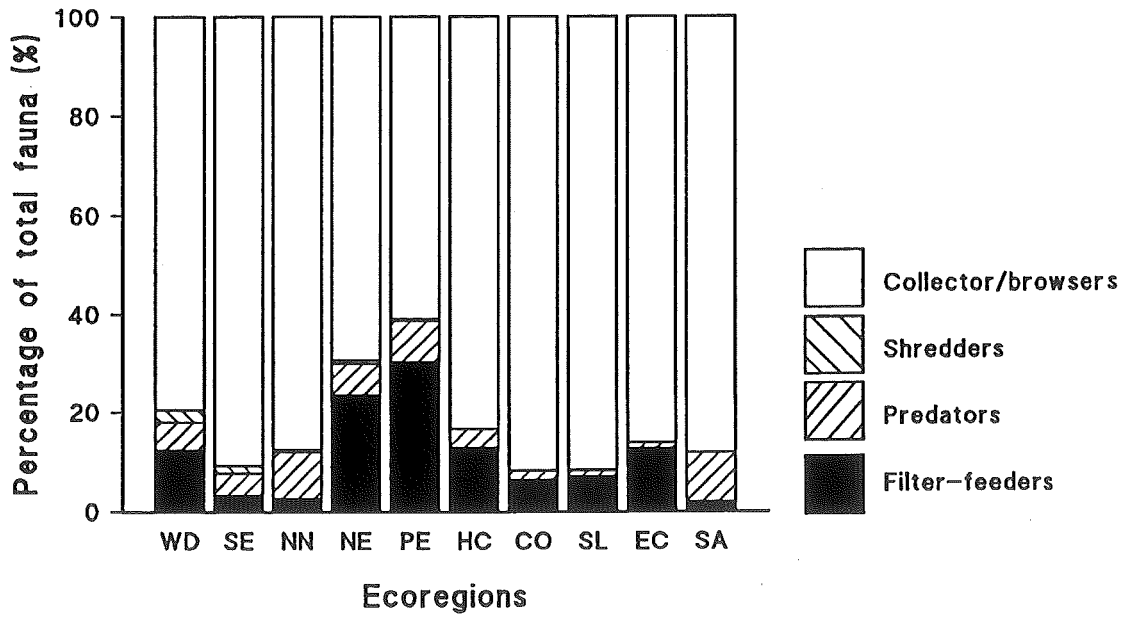


Figure 3.5 Mean percentage contributions of four functional feeding groups in each ecoregion (n=10).

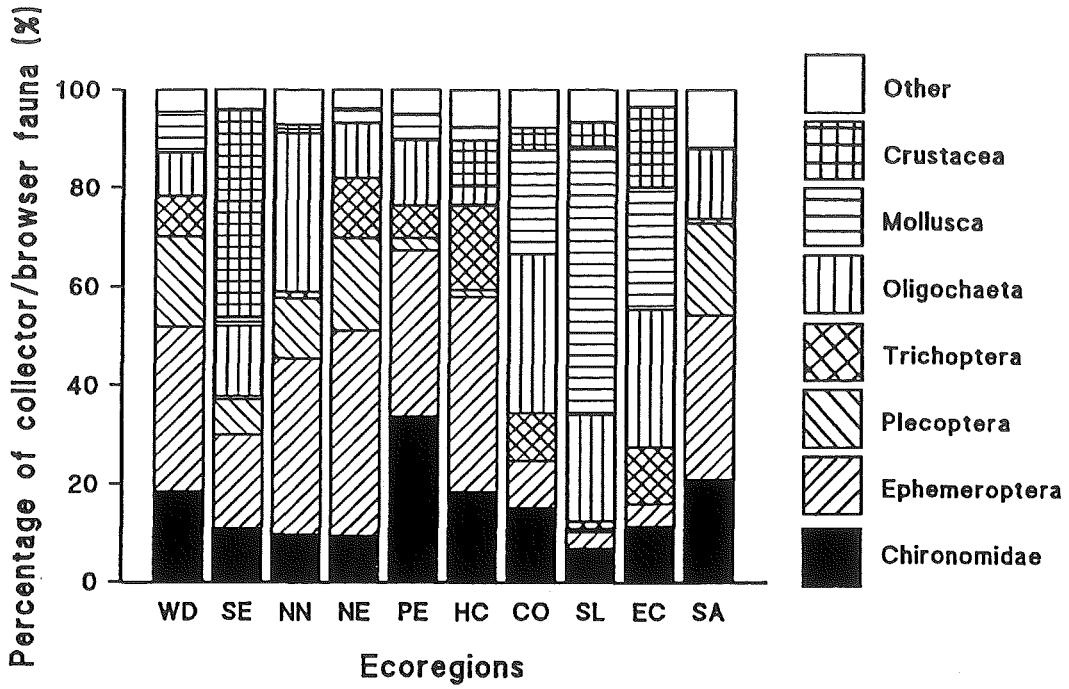


Figure 3.6 Mean percentage contribution of major taxonomic groups to the collector/browser functional feeding group, in each ecoregion (n =10).

The Predator functional feeding group was also a minor component of stream faunas in most ecoregions. The highest predator relative abundances occurred in Southern Alps and North-west Nelson streams, but predators were poorly represented in the three pastoral ecoregions (Fig. 3.5).

The percentage of shredders was very low in all ecoregions, with the highest abundances occurring in Westland and South-east Forest streams. Shredders were rare or absent from Southern Alps, Central Otago, Southland Plains and East Coast Plains streams (Fig. 3.5).

Community composition

Several taxa had wide-ranging distributions within the South Island, in particular, the ephemeropteran *Deleatidium* (Leptophlebiidae). It was the most abundant taxon in seven ecoregions, however, it was not among the five most abundant taxa in Southland and East Coast streams, and was only fifth most abundant in Central Otago streams (Table 3.3). Other widely distributed taxa were *Potamopyrgus antipodarum* (Gastropoda: Hydrobiidae),

Table 3.3 The five most abundant taxa in order of frequency of abundance in streams of each ecoregion (n = 10 streams per ecoregion).

	Order of abundance				
	1	2	3	4	5
WD	*Deleatidium* spp.	*Coloburiscus humeralis*	*Austroperla cyrene*	*Polypedilum* sp.	*Rakiura vernale*
SE	*Deleatidium* spp.	*Paracalliope* spp.	*Stylodrilus* sp.	*Paraleptamphopus subterraneus*	*Hydrobiosella stenocerca*
NN	*Deleatidium* spp.	*Nais* sp.	*Paucispinigera* sp.	*Zelandobius furcillatus*	*Zelandobius confusus*
NE	*Deleatidium* spp.	*Zelandobius confusus*	*Diplectrona zelandensis*	*Coloburiscus humeralis*	*Nais* sp.
PE	*Deleatidium* spp.	*Coloburiscus humeralis*	Macropelopiini	*P. antipodarum*	*Eukiefferiella* sp.
HC	*Deleatidium* spp.	*Aoteapsyche colonica*	*Olinga feredayi*	*Maoridiamesa* sp.	Simuliidae
CO	*Stylodrilus* sp.	Simuliidae	*P. antipodarum*	Elmidae	*Deleatidium*
SL	*Potamopyrgus antipodarum*	*Stylodrilus* sp.	Elmidae	*Eukiefferiella* sp.	*Physa acuta*
EC	*Potamopyrgus antipodarum*	*Paracalliope* sp.	*Limnodrilus* sp.	*Stylodrilus* sp.	*Sphaerium novaezelandiae*
SA	*Deleatidium* spp.	*Eukiefferiella* sp.	*Zelandobius furcillatus*	*Maoridiamesa* sp.	*Telmatodrilus multiprostatus*

Elmidae (Coleoptera), and Simuliidae (Diptera) (Table 3.4).

Several taxa, were consistently associated with specific vegetational and land use types. The bivalve *Sphaerium novaezelandiae*, the introduced gastropod *Physa acuta* and the caddis *Oxyethira albiceps* (Hydroptilidae) were most commonly associated with pastoral streams in the East Coast and Southland Plains (Table 3.4). Several plecopterans including *Stenoperla prasina* (Eustheniidae), *Austroperla cyrene* (Austroperlidae), and the gripopterygids *Zelandoperla decorata*, and *Zelandobius* spp. were most commonly found in forested streams in the two Nelson ecoregions, Westland and the South-east forest (Table 3.4).

The distributions of several other taxa appeared to be primarily geographical rather than dependent on vegetation/land use. *Rakiura vernale* (Trichoptera: Helicopsychidae) was collected in Westland, North-west Nelson, and the South-east Forest (specifically Stewart Island) ecoregions, and was among the five most abundant invertebrate taxa in Westland streams (Table 3.3). Similarly, *Paraleptamphopus subterraneus* (Crustacea: Amphipoda) was only collected in the South-east Forest ecoregion, and was among the most abundant taxa there. Furthermore, *Diplectrona zelandensis* (Trichoptera: Hydropsychidae) was among the most abundant taxa in North-east Nelson, but was only collected in three regions; North-east and North-west Nelson and Westland.

Multivariate analysis using TWINSPAN and presence/absence data separated the streams at the first division into closed canopied sites (all streams in Westland, South-east Forest, both Nelson ecoregions and six streams in the Banks Peninsula ecoregion) and sites in exposed or open-canopied catchments of Central Otago, Southland, East Coast Plains, the Southern Alps, and the four remaining Banks Peninsula streams (Fig. 3.7). Division of this open-canopied group separated streams in the three intensively farmed ecoregions, i.e. Central Otago, Southland and East Coast Plains from the High Country and Southern Alps streams. Subsequent divisions did not distinguish communities in Central Otago, Southland and East Coast Plains streams along ecoregion boundaries, however, High Country and

Table 3.4 List of taxa collected in at least 6 streams within an ecoregion.

	EC	SL	CO	SA	HC	PE	NE	NN	SE	WD
PLATYHELMINTHES										
Neppia montana	+	+			+	+	+			+
ANNELIDA										
Lumbriculus variegatus										+
Telmatodrilus multiprostatus				+						
Stylodrilus sp.	+	+	+						+	
Nais sp.							+	+		
MOLLUSCA										
Potamopyrgus antipodarum	+	+	+		+	+	+		+	
Physa acuta	+	+								
Sphaerium novaezelandiae	+	+								
CRUSTACEA										
Paracalliope sp.	+								+	
INSECTA										
EPHEMEROPTERA										
Coloburiscus humeralis					+	+	+			+
Nesameletus sp.						+	+	+		
Ameletopsis perscitus										+
Neozephlebia scita						+	+			
Zephlebia dentata							+	+		
Deleatidium spp.	+		+	+	+	+	+	+	+	+
Austroclima jollyae										+
PLECOPTERA										
Stenoperla prasina							+	+	+	+
Austroperla cyrene						+	+	+	+	+
Zelandoperla decorata					+	+	+	+	+	
Zelandobius confusus							+		+	
Zelandobius furcillatus						+		+		+
Cristaperla fimbria							+	+		
Megaleptoperla diminuta									+	
MEGALOPTERA										
Archichauliodes diversus					+	+				
COLEOPTERA										
Elmidae	+	+	+		+		+	+		
DIPTERA										
Eriopterini sp.		+						+	+	
Nothodixa sp.									+	
Eukiefferiella spp.		+	+	+	+	+				
Paucispinigera approximata								+		
Polypedilum spp.							+			
Macropelopiini sp.						+				
Diamesinae indet.									+	
Maoridiamesa sp.					+	+				
Cricotopus spp.			+							

Table 3.4 (continued)

	EC	SL	CO	SA	HC	PE	NE	NN	SE	WD
Simuliidae	+	+	+		+	+	+		+	+
Tanyderidae						+				
Empididae sp. A					+	+				
Empididae sp. B (hairy)									+	
Muscidae		+								
Paralimnophila skusei									+	
Aphrophila neozelandica					+					
TRICHOPTERA										
Diplectrona zelandensis							+	+		
Aoteapsyche colonica			+		+	+	+			
Hydrobiosella stenocerca							+	+	+	
Hydrobiosis silvicola										+
Hydrobiosis parumbripennis	+	+	+		+	+				
Psilochorema nemorale	+	+			+		+		+	+
Olinga feredayi					+	+	+			
Helicopsyche spp.					+	+	+			
Rakiura vernale								+		+
Pycnocentria evecta	+		+		+		+			
Pycnocentrodes spp.	+				+					
Hudsonema amabilis	+		+							
Oxeythira albiceps	+	+								

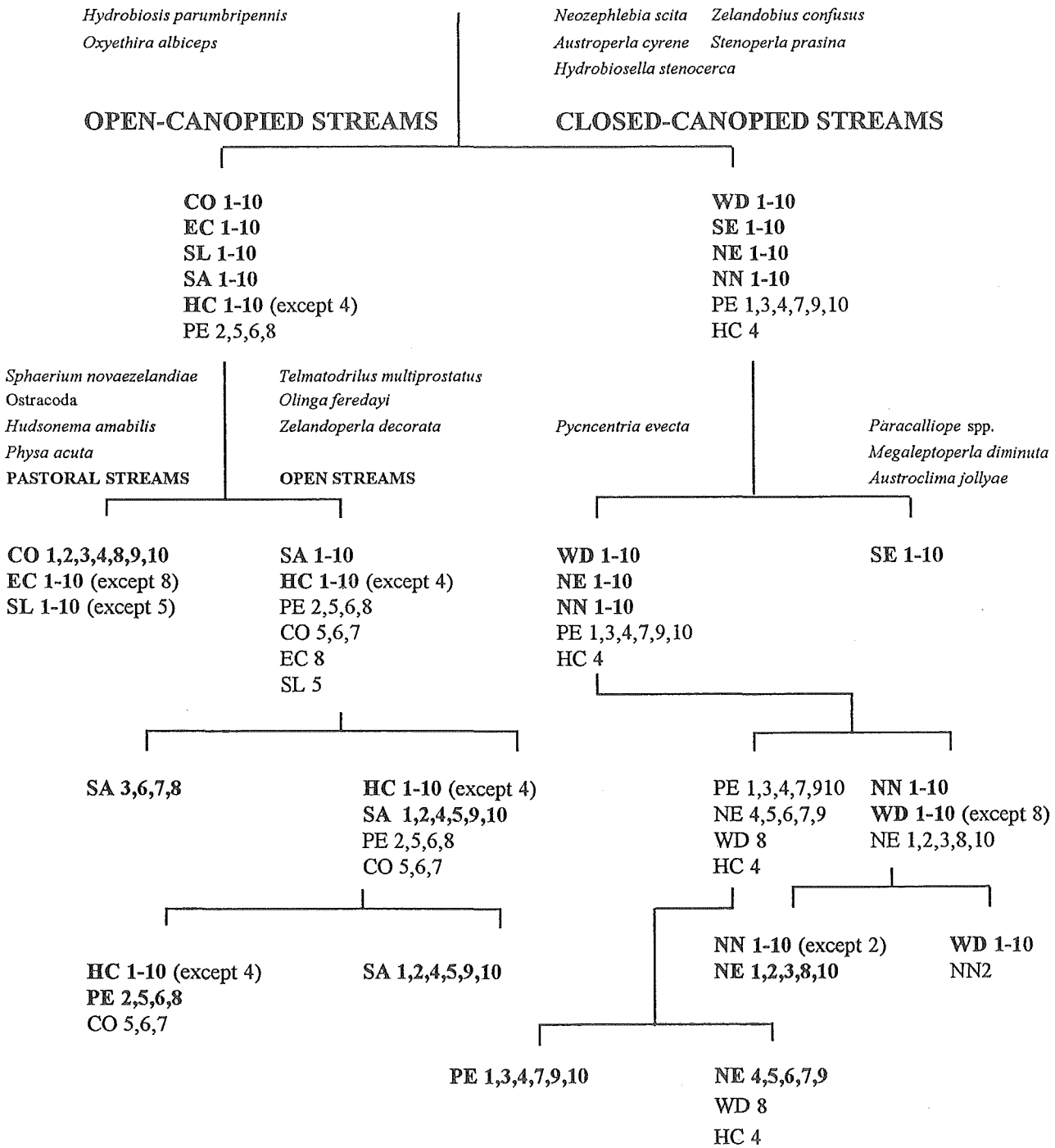


Figure 3.7 Classification of the 100 streams using TWINSPAN and presence/absence data. The predominant ecoregion groups are shown in bold, and indicator species for the main bifurcations are given in italics.

Southern Alps streams were separated into two Southern Alps groups and a High Country cluster.

The first division of the 'closed' canopy stream group placed all the South-east Forest streams into a single cluster. Further divisions of the remaining streams separated the two Nelson and Westland ecoregions from the remaining Banks Peninsula and five North-east Nelson streams. Westland streams were then separated from those in North-west Nelson and the five remaining North-east Nelson sites. A final division of the remaining Banks Peninsula and North-east Nelson streams separated these two ecoregions (Fig. 3.7).

DECORANA separated pastoral, open canopied streams from streams in forested ecoregions along Axis 1. However, High Country, Banks Peninsula, and Southern Alpine streams were intermixed between them (Fig. 3.8). No discernable patterns in the distributions of streams were found along Axes 2 and 3. DECORANA eigenvalues indicated

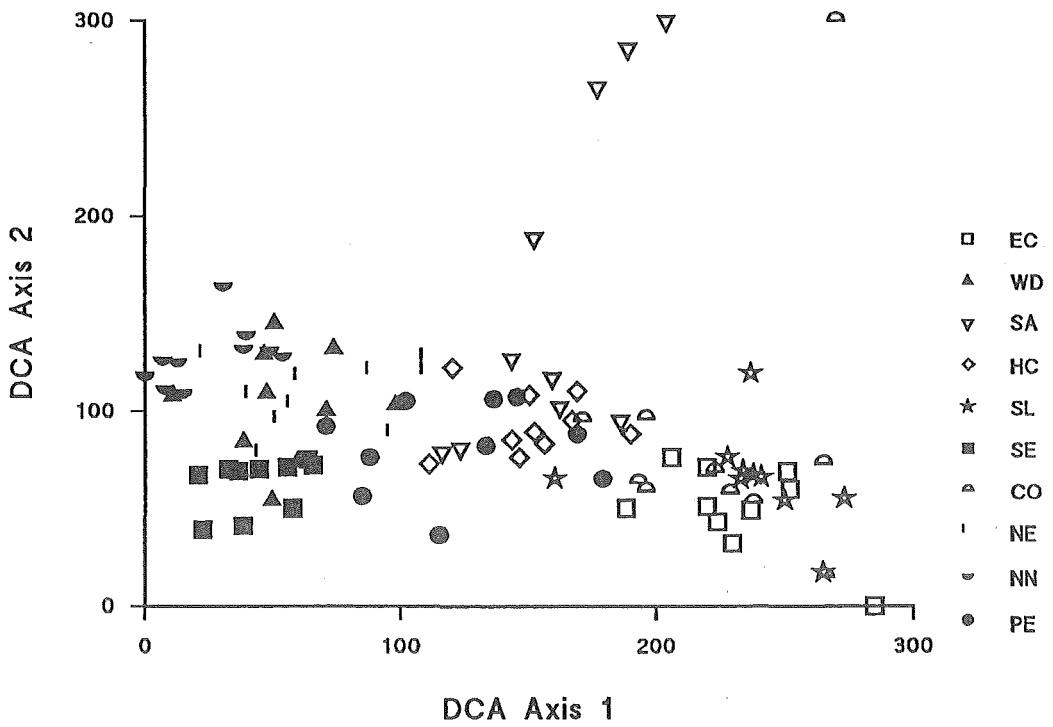


Figure 3.8 Ordination of 100 streams based on presence/absence data.

that Axis 1 accounted for 48%, Axis 2 for 29% and Axis 3 for 23% of the total variance explained by the three axes.

Because neither TWINSPAN nor DECORANA could separate Central Otago, Southland and East Coast Plains streams using presence/absence data a further DECORANA was undertaken using quantitative data for these 30 streams. Again, no clear separation of streams into independent ecoregion clusters was apparent (Fig. 3.9).

Discussion

The primary objective of the work addressed in this chapter was to test whether the lotic ecoregions defined in Chapter 1 had distinct stream faunas. The comparisons of abundance, taxonomic richness and community composition indicate that the "pristine" and climatically harsh ecoregions of the west and north were distinguishable on this basis,

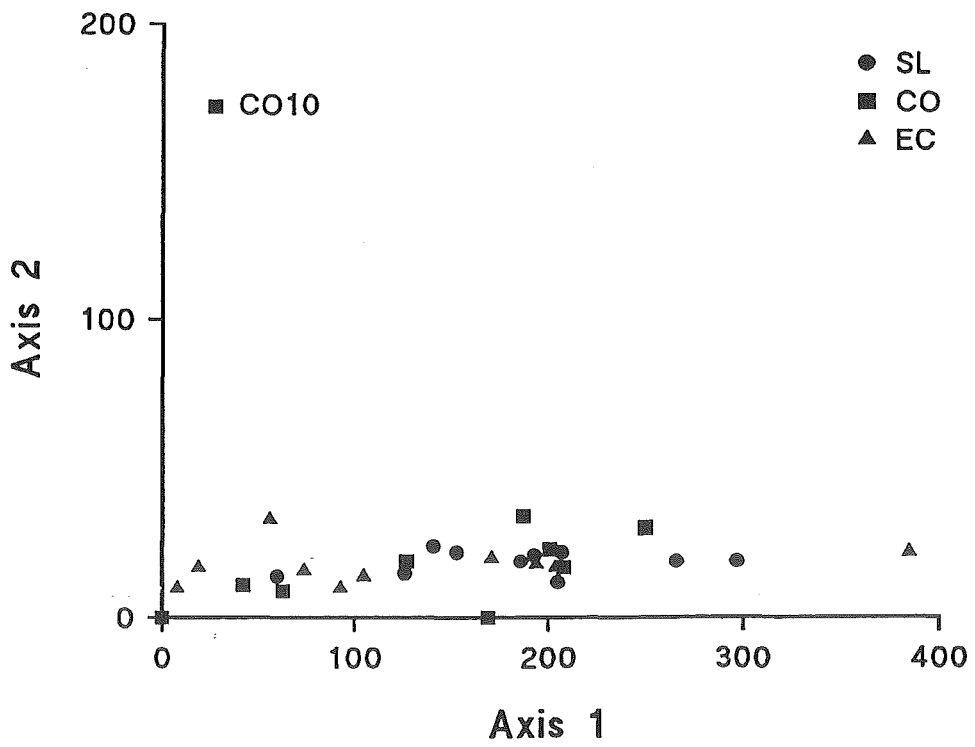


Figure 3.9 Ordination of the 30 streams in the three pastoral ecoregions (CO, SL and EC) using quantitative data. The "outlier" stream CO10 had few species and very low densities in comparison to the other 29 streams.

however as both the level of anthropogenic influences (i.e. deforestation, farming and pollution) increases, and climatic extremes lessen, the distinctiveness of an ecoregion's stream fauna diminishes. The results of my study indicate that three primary macro-environmental conditions were paramount in influencing the composition of South Island benthic communities; past biogeographical events, vegetation and land use patterns, and present climatic conditions.

Circumstantial evidence implicates past biogeographical events in influencing the present composition of the stream faunas of several ecoregions. Thus, I found that taxonomic richness was greatest in Westland, North-east Nelson and North-west Nelson. This high taxonomic richness in the west and north of the South Island is consistent with suggestions by other workers that they may be areas of high endemism (Cowley 1978, Cowie 1980, Henderson 1983, Collier & Winterbourn 1987). Westland streams were found to be rich in plecopteran, trichopteran, coleopteran and dipteran taxa, and high plecopteran diversity was also reported by Cowie (1980) who collected 13 plecopteran taxa in Devils Creek, near Reefton, and by Collier & Winterbourn (1987) who found 13 species in four South Westland streams. In my survey, 16 plecopteran taxa were collected from streams in Westland, 14 being species of Gripopterygidae and Notonemouridae. The highest numbers of trichopteran taxa were also found in Westland and North-west Nelson. Henderson (1983) suggested that North-west Nelson was an area of high trichopteran speciation, and Collier (1993) reported at least 12 taxa that are apparently restricted to this region. I found 26 trichopteran taxa in North-west Nelson streams, including three unidentified species that were not collected in other ecoregions. A similar situation was found in Westland streams where I collected 30 taxa, including an undescribed *Diplectrona* species.

Collier (1992, 1993) identified 154 freshwater species (excluding subterranean taxa) believed to have restricted distributions on the mainland of New Zealand. The distribution of these "rare" species amongst my ecoregions confirms the high endemism of the overall freshwater fauna of Westland (not just the low order stream fauna), and to a lesser extent the

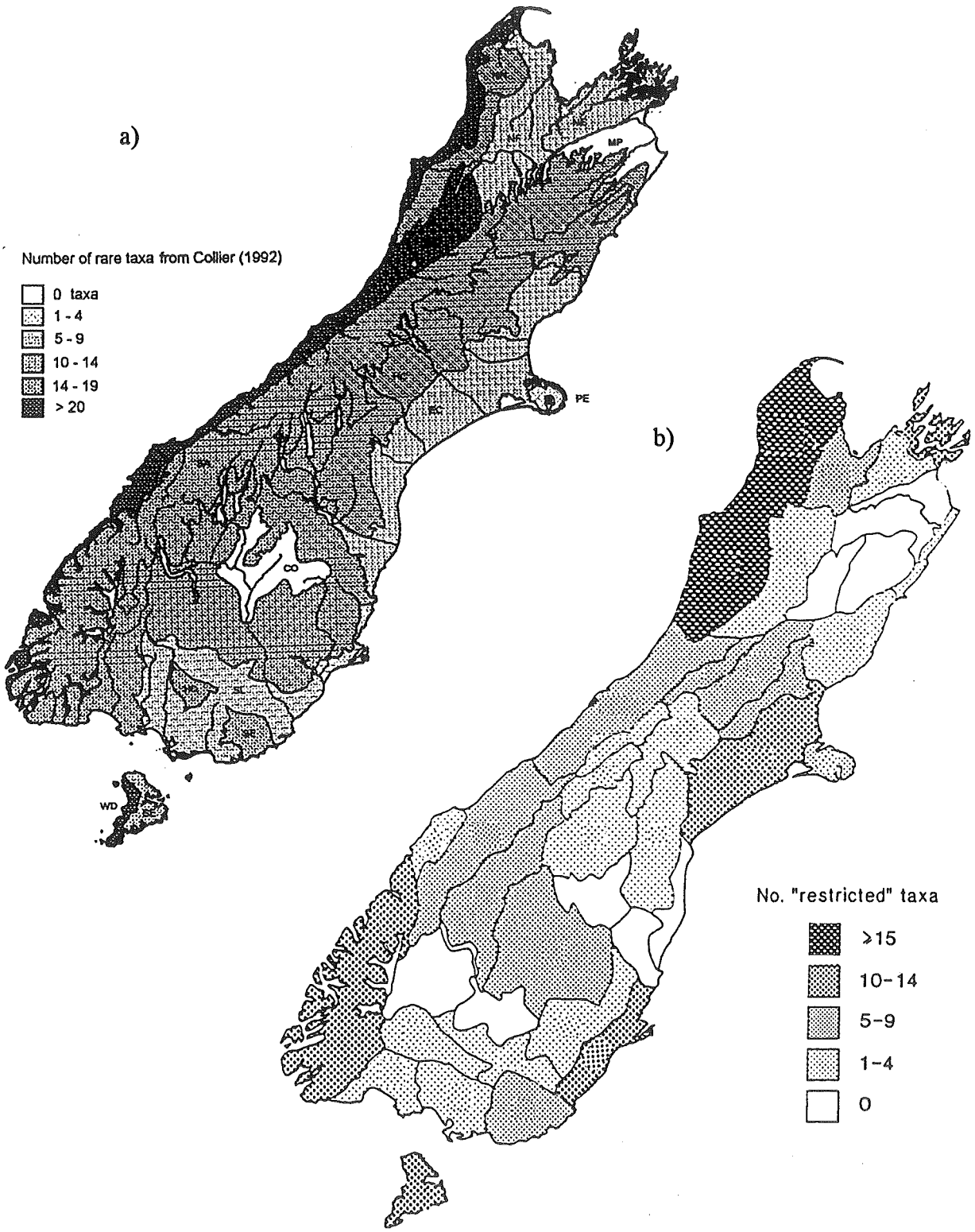


Figure 3.10 a) Map of the South Island showing the lotic ecoregions shaded according to the number of invertebrate species with restricted distributions (i.e recorded in a single ecoregion only)(data from Collier 1992); b) Map from Collier (1993) showing numbers of taxa restricted to less than 4 of the Ecological regions of McEwen (1987).

faunas of North-west Nelson, the Southern Alps and the High Country (Fig. 3.10). However, information on the distributions of many taxa is limited by a lack of sampling effort by stream biologists in isolated and inaccessible catchments in much of the South Island. Ross (1963) hypothesised that in North America species diversity, is likely to be greater in small, headwater streams in forested catchments, than in larger rivers. Comparisons with data on species richness in 31 South Island rivers obtained as part of the 100 rivers project (Quinn & Hickey 1990) supports this contention; an average of 14 taxa were collected per river in their study compared with an average of 23 in my streams. Furthermore, my intensive sampling within 10 South Island ecoregions indicates that numerous undescribed taxa still exist, and that several ecoregions, specifically Westland, North-west Nelson and North-east Nelson had higher numbers of these undescribed species.

Several ecoregions were characterised by taxa that had limited geographical distributions and were sometimes locally abundant. The trichopteran *Rakiura vernale* was one of the most abundant taxa in Westland, and has only been collected from this region, North-west Nelson and Stewart Island (Michaelis 1973, Cowley 1978, Chadderton 1988, Winterbourn & Collier 1987, Winterbourn & Gregson 1989). Michaelis (1973) considered it to be a "glacial relict" restricted to cold spring waters (e.g. in North-west Nelson) and Stewart Island, but she was unaware of its widespread distribution in coastal Westland where water temperatures are more moderate (see Graesser 1988). The reasons for its restricted, western distribution remain unclear. The hydropsychid caddis *Diplectrona zelandensis* was also found only in Westland, North-west and North-east Nelson in my study and has not been reported elsewhere in the South Island by other workers (Collier 1992). It is widely distributed in the south of the North Island particularly around Wellington (Cowley 1978), and has a distribution pattern apparently unlike that of other freshwater insects. The blephariceríd *Neocurupira chiltoni* is found only on Banks Peninsula where it is endemic and widespread (Craig 1969).

The high taxonomic diversity and limited geographical distributions of several taxa in the Westland, North-west and North-east Nelson ecoregions may be partially explained by

past biogeographical events. Henderson (1983) noted that locally endemic trichopteran distributions are congruent with paleographical events such as the presence of a Pliocene sea barrier in the region of Manawatu (North Island), a hypothesis further supported by distributions of some Blephariceridae (Craig 1969). Regions of high diversity today may have resulted from the creation of refugia from Pleistocene glaciations, a hypothesis supported by several workers (Fleming 1962, McLellan 1977, Cowley 1978, Fleming 1979, Henderson 1983), although this does not satisfactorily account for the lack of dispersal of these species after the glacial retreat. Most adult trichopterans, for example, are active fliers, and the elapse of approximately 10,000 years since the last major glaciation should have provided sufficient time for dispersal of many of these species (Figure 3.11 shows the estimated extent of glacial advances). An alternative hypothesis, is that the distributions found today reflect more recent climatic changes that occurred subsequent to the Pleistocene glaciations (Cowie 1980).

In addition to biogeographical factors, major macro-environmental factors influencing diversity and composition of invertebrate faunas in South Island streams are catchment vegetation and land use activities. TWINSPAN analysis separated forested (closed canopy) ecoregions from those with open-canopied streams. Towns (1979) and Cowie (1980) also found high species diversities and distinctive communities in kauri and beech forest streams. In contrast, low taxonomic diversity has been reported widely in streams in pastoral land (Taranaki Catchment Commission 1984, Quinn & Hickey 1990), and the members of some taxonomic groups including many Plecoptera cope poorly in open, lowland streams where temperatures rise above critical levels, sediment yields are high and low dissolved oxygen concentrations occur (Quinn & Hickey 1990). Graynoth (1979) noted that plecopteran abundances were greatly reduced in recently logged streams in Nelson, and suggested that both increased sediment concentrations and elevated temperatures may have been responsible. The importance of climate is also indicated by the low diversity and low invertebrate densities recorded in Alpine streams which provide highly unstable, physically

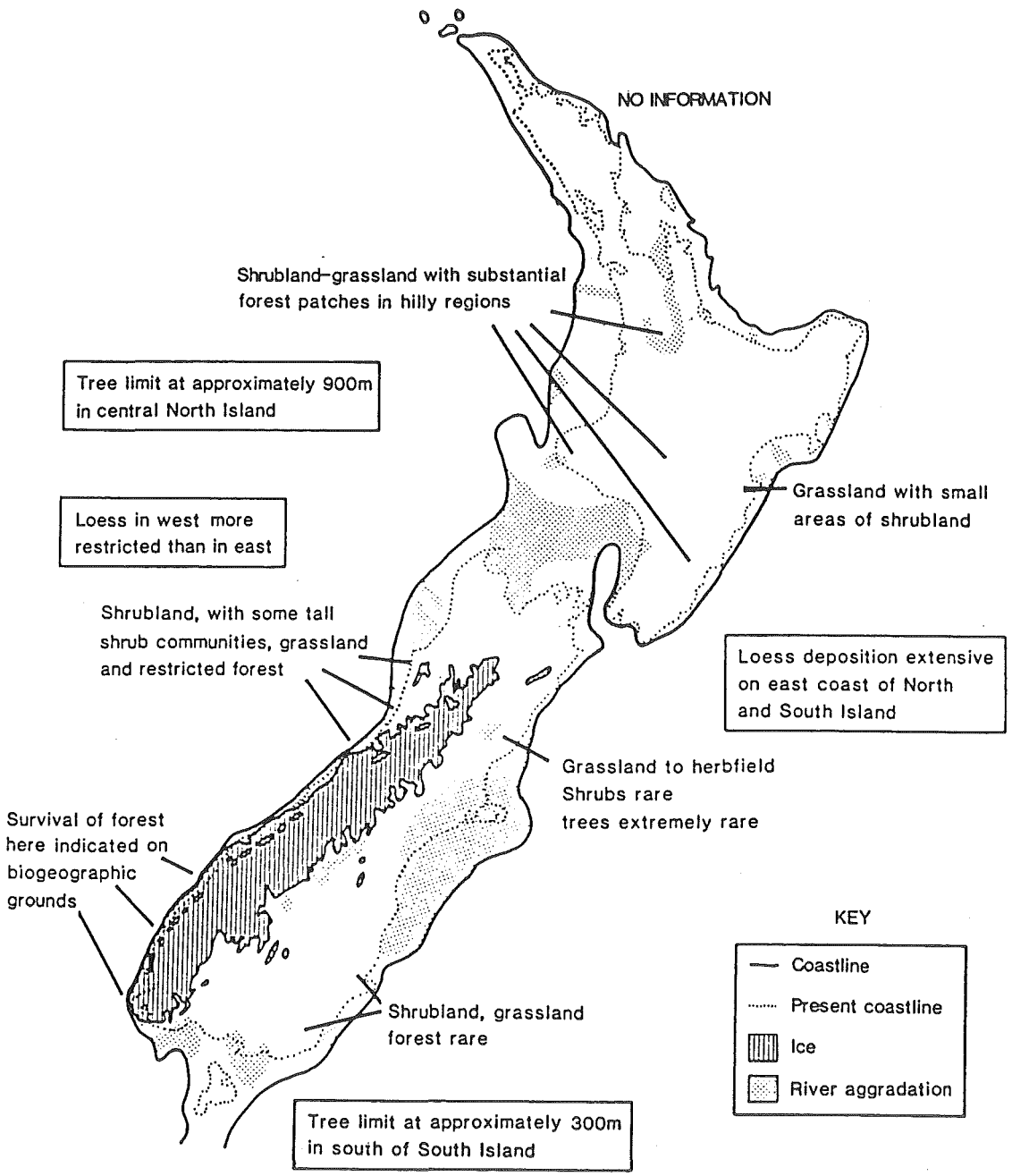


Figure 3.11 New Zealand during the last glaciation, 22,000 to 14,000 yrs B.P. No reliable information is available for Northland (from McGlone 1985).

harsh environments (and see Winterbourn & Ryan 1994). The Alpine ecoregion has some of the highest rainfall in New Zealand, and sediment yields are amongst the highest in the world (Griffiths 1979). Hence faunal persistence in many high altitude South Island streams is likely to be strongly affected by the highly unstable nature of the environment. Furthermore, the taxa inhabitating these streams are almost certainly those species least effected by natural catastrophic disturbances, and/or those species able to recover or recolonise quickly. The fauna I collected in Southern Alps streams was generally of low diversity and similar to the faunas of large, flood-prone rivers in lowland regions (Sagar 1986, Scrimgeour et al. 1988, Scrimgeour & Winterbourn 1989). Similarly, Quinn & Hickey (1990) found significantly lower taxonomic richness and invertebrate biomass in rivers prone to severe flooding.

The relative abundances of different "functional feeding groups" in the 10 ecoregions did not differ greatly, partly due to the paucity of shredders, even in forested streams. This is a distinctive feature of New Zealand stream communities (Winterbourn et al. 1981) and one confirmed by my extensive study. The usefulness of functional feeding groups for interpreting community relationships in New Zealand streams was limited. This is not altogether surprising as the larvae of many New Zealand stream insects show little evidence of either food specialisation or habitat preferences (Winterbourn et al. 1981, Jowett & Richardson 1990, Death 1991). Approximately 85% of the larvae in Devils Creek, near Reefton fed on epilithon and associated FPOM (Cowie 1980), while Death (1991) concluded that 60-90% of the fauna of 15 High Country streams were collector-browsers that feed on stone-surface organic layers and FPOM. Similarly, 75-90% of the invertebrates collected from each South Island ecoregion belonged to this relatively unspecialised functional feeding group.

The Westland, North-west and North-east Nelson, Banks Peninsula, High Country and Southern Alps ecoregions all had high percentages of ephemeropteran collector-browsers, primarily the leptophlebiid *Deleatidium*. The dominance of *Deleatidium* in New Zealand streams has been widely documented (Pierce 1979, Sagar 1986, Winterbourn & Collier

1987, Scrimgeour et al. 1988, Scrimgeour & Winterbourn 1989), and the success of this genus has been related to its generalised habitat and food requirements (Jowett & Richardson 1990, Collier 1994, Winterbourn & Ryan 1994), and its ability to resist and/or recover quickly from floods (Scrimgeour et al. 1988, Death 1991). In contrast, crustacean collector-browsers particularly the amphipods *Paracalliope* spp. and *Paraleptamphopus subterraneus* were abundant in some but not all streams of the South-east Forest ecoregion. *P. subterraneus* is also found in springs, subterranean waters and intermittent streams (Death 1991), and *Paracalliope fluviatilis* is a characteristic inhabitant of vegetated lowland rivers. The benthic communities of streams in the three pastoral ecoregions were dominated by oligochaetes and gastropod molluscs, which can also be categorized as collector-browsers. The common snail, *Potamopyrgus antipodarum* was among the five most abundant taxa in all three regions. Both Oligochaeta and *P. antipodarum* were also important components of the faunas of small, enriched, open-canopied lowland streams in the survey of 88 rivers by Quinn & Hickey (1990). *P. antipodarum* is often abundant in lakes (Timms 1982), springs (Michaelis 1974), lake outlets (Harding in press), and stable streams with abundant epilithic communities (Death 1991).

By what means is the distinctiveness of the stream invertebrate communities in each ecoregion best reflected? Firstly, comparison made on the basis of taxonomic richness provided a useful method of distinguishing closed-canopy from open-canopied ecoregions. A considerable disparity was evident in the species richness of major invertebrate orders, especially the Ephemeroptera and Plecoptera. In contrast, invertebrate densities varied greatly within and between ecoregions and did not provide informative evidence of ecoregion differences. However, the dominance and frequency of occurrence of individual taxa resulted in the effective differentiation of otherwise seemingly similar faunas. Multivariate analysis of community composition, especially the use of TWINSPAN supported the conclusions derived from the frequency of occurrence data. Both dominance and frequency of occurrence and TWINSPAN presence/absence analyses were probably less

influenced by recent disturbance events or intra-catchment variability than density data, and indicated uniformity in the composition of ecoregional faunas. They were also more informative than data on functional feeding groups, which indicated only gross differences between ecoregion communities.

The inability of multivariate techniques (using both presence/absence and quantitative data) to distinguish between the streams of the three pastoral ecoregions raises the question of the purpose of this ecoregional framework - is it designed to represent "pristine" unmodified streams within an ecoregion, or the condition of presently typical streams (anthropogenically effected or otherwise). If this classification is to be useful to conservators, river managers and local authorities then it must represent existing conditions within each ecoregion. If this is the case, then the faunas of the three pastoral ecoregions are not distinguishable at the community level. However, the abundance and frequency of occurrence of taxa within each of these ecoregions does differ. For example, the trichopterans, *Pycnocentria evecta*, *Pycnocentrodes* spp. and *Oxyethira albiceps* were collected in all three ecoregions, however, in Southland Plains they were found in low numbers, and only in a few streams, whereas in the East Coast Plains the same taxa were collected in almost all streams and usually in higher densities.

The results of my macroinvertebrate sampling programme indicate that biogeographical, vegetation, land use, and climatic effects can strongly influence the composition of stream communities. Furthermore, my findings indicated the need to investigate further the effects of different land use activities on benthic communities. Such an investigation was therefore conducted in four land use types near Hamner Springs (High Country ecoregion) and is discussed in Chapter 5.

Chapter 4

Stream water chemistry: comparisons among ecoregions

Introduction

The chemical composition of river water is a product of the lithology of the catchment, atmospheric inputs, climatic conditions, land use practices and stream biota (Stumm & Morgan 1981, Drever 1982, Grip 1982, Maasam & Smith 1994). Of these factors, the major source of dissolved ions is usually catchment bedrock, as shown in numerous studies of stream water chemistry and catchment geology (Miller 1961, Hughes & Edwards 1977, Johnson & Reynolds 1977, Grip 1982). The chemistry of most unpolluted surface and groundwaters is primarily a result of the interaction of bedrock materials and climatic conditions (Drever 1982), and generally, the composition of runoff waters will reflect the nutrients available in the soil or rock through which it passes. Exceptions are those situations in which the residence time of the water is low, and where surface water chemistry is likely to be closer in composition to that of precipitation (Bache 1983). Particularly good examples of substrate-mediated water chemistry conditions are found in the Central North Island of New Zealand where volcanic formations have phosphorus enriched waters (Currie & Gilliland 1980, Timperley 1983). In contrast, freshwater systems in granite and limestone regions can receive high inputs of nitrates from the bedrock (Lay & Ward 1987), and bicarbonate and alkalinity values are likely to be elevated (Stumm & Morgan 1981).

The water chemistry of New Zealand rivers has been the subject of increasing numbers of studies that have dealt with water clarity (Davies-Colley 1990), the effects of differing land use activities and resultant eutrophication (McColl et al. 1975, McColl et al. 1977, McColl & Hughes 1981, Mosley & Rowe 1981, Burden 1982), and chemical water quality in general (Bargh 1978, Hoare 1982, McColl 1982, Williamson & Cooke 1982,

Close & Davies-Colley 1990a,b, Stenzel & Herrmann 1990).

Several studies on water quality have been conducted at the regional level, particularly by (the former) Catchment Boards (e.g. the Taranaki Ring plain study; Taranaki Catchment Commission 1984), however, few large scale investigations have been undertaken. Mosley (1982) surveyed the temperatures of a number of major rivers throughout New Zealand, and Biggs & Price (1987) investigated algal communities nationwide with reference to water temperature and conductivity. However, the most comprehensive water quality survey of lotic waters in New Zealand has been the "100 rivers" project in which 96 rivers were chemically characterised and associated with environmental conditions (Close & Davies-Colley 1990a,b). Close & Davies-Colley (1990b) found that bedrock geology and the degree of catchment development influenced the concentrations of certain chemical ions in stream waters. In particular, high altitude stream catchments devoid of soft, sedimentary bedrock had low concentrations of all ions, whereas streams in volcanically derived catchments had waters high in phosphorus. Nitrate and to a lesser extent phosphorus concentrations were usually elevated in agriculturally developed catchments.

Bedrock geology and catchment soil type were important factors used to delineate the lotic ecoregions defined in Chapter 1. As these two components differed to varying degrees among regions, often substantially, it seemed likely that stream water chemistry would also vary in a corresponding manner. The primary aim of my water sampling programme was to characterise the water chemistry of the 100 small headwater streams used in testing the ecoregion classification (see Chapter 2). Secondly, I wished to determine whether streams in the 10 ecoregions were distinctive in terms of water chemistry, and whether they were more clearly distinguished in this way, than using biological (macroinvertebrate) criteria.

Materials and methods

Water samples were collected from 10 headwater streams in each of 10 South Island

ecoregions over the summers of 1993-1994 (sites are described in Chapter 2 and Appendix 2). Each stream was sampled once under baseflow conditions, and at least three days after a storm event. Samples were collected in 500 ml opaque, polyethylene bottles, kept cool, and returned to the laboratory for analysis. Conductivity was measured with a Hanna HI 8633 meter and expressed as μS cm^{-1} at 25°C; pH was determined with a Metrohm Herisau E488 pH meter and electrode. Total alkalinity was estimated by titration with 0.01N HCl to pH 4.5 (Golterman & Clymo 1969). Two 40 ml subsamples were filtered through glass-fibre filters (Gelman, type A/E) before 1-2 drops of conc HNO_3 were added to one subsample and 1-2 drops of 40% formalin were added to the second. These were sent to Dr. Wayne McDiffett at Bucknell University, Pennsylvania for analysis of cations (sodium, potassium, calcium, magnesium, iron, manganese and total aluminium) by atomic absorption spectrometry (Video 12aa/ae Spectrophotometer), and anions (chloride, nitrate-N, sulphate, and phosphate-P) by ion chromatography (Dionex Series 4000i). Minimum detectable levels of nitrate-N and phosphate-P were 0.01 mg l^{-1}. Water chemistry conditions for each stream is given in Appendix 4.

At each sampling site information on percentage of the catchment in different bedrock and soil types including schist (%SCHIST), soft sedimentary rocks (%SOFTSED, i.e. sandstone, mudstone, limestone), hard sedimentary rocks (%HARDSED, i.e. greywacke), and volcanic rocks (%VOLC), and major soils classes (i.e. loess, and alluvium) were estimated from Land Resource Inventory maps (1: 63 360; NWASCO 1975-79).

Major anion and cation concentrations in all stream water samples from each ecoregion were converted to milliequivalents per litre by multiplying the quantity of each ion in the stream by the atomic weight of the ion and dividing by the ionic charge. Milliequivalent values were plotted as Stiff diagrams which were interpreted by comparing the diagram shape for each ecoregion and the ratios of major anions and cations (Stiff 1951).

Statistical analysis

Comparisons of anion and cation concentrations between ecoregions were compared

by ANOVA. Data were first tested for normality and homoscedasticity, and values with unequal variances were log transformed. Following a significant ANOVA ($P<0.05$), comparisons of means were made with Tukey's HSD test (STATISTIX 3.5: Analytical Software 1991). Data that could not be transformed successfully were analysed statistically using the non-parametric Kruskal-Wallis test (Sokal & Rohlf 1981). Significance was accepted at $P<0.05$.

The distinctiveness of the water chemistry profiles of streams within and between ecoregions was assessed using the complete water chemistry data by multivariate analysis. Initially, correlations among chemical variables were examined (Table 4.1), and those with high cross-correlations ($P < 0.01$) were combined; this reduced the total number of variables to eight. All data were normalised by conversion to a 0-1 scale (using STATISTIX 3.5) to overcome differences in variable units, and an average calculated for the cross-correlated variables (Close & Davies-Colley 1990b). The 8 final "combined" variables used for making comparisons among ecoregions were;

MAJOR IONS = (Conductivity + Cl + Mg + Na + K + SO_4)/6

ACIDITY = (pH + Alkalinity)/2

Ca, Mn, PO_4-P, Fe, Al, and NO_3-N.

The complete set of 8-variable water chemistry data for the 100 streams was then examined

Table 4.1. Spearman rank correlation coefficients for water quality variables calculated from data for the 100 streams ($P<0.01$**, $P<0.05$*).

	pH	Cond	Na	K	Ca	Mg	Fe	Mn	Al	Cl	SO_4	NO_3-N	PO_4-P
Cond	0.22*												
Alk	0.40**	0.51**	0.23*	0.08	0.13	0.30**	-0.11	-0.02	-0.03	0.33**	0.29**	0.35**	0.13
Na	0.11	0.64**		0.72**	0.08	0.80**	0.34**	0.29**	0.09	0.64**	0.49**	0.44**	-0.02
K	-0.03	0.54**			0.15	0.58**	0.34**	0.26**	0.13	0.30**	0.29**	0.41**	-0.01
Ca	0.39**	0.17				0.37**	0.16	0.09	-0.27**	-0.10	0.16	-0.07	0.07
Mg	0.24*	0.66**					0.32**	0.35**	0.11	0.58**	0.50**	0.32**	-0.08
Fe	-0.04	0.22						0.22	0.15	0.05	0.12	0.09	0.09
Mn	0.28**	0.19							0.07	0.21*	0.42**	-0.02	-0.05
Al	-0.20	0.24*								0.30**	-0.06	0.25*	0.01
Cl	0.03	0.51**									0.44**	0.24*	0.14
SO_4	0.26*	0.40**										0.13	-0.11
NO_4-N	0.01	0.52**											-0.03
PO_4-P	-0.01	-0.01											

using cluster analysis. A modified version of Sorensen's quotient of similarity that utilized the normalised quantitative data for the eight variables was used to develop a similarity matrix and the group average clustering method was used for clustering (McCune 1991).

Detrended correspondence analysis (DECORANA: Hill 1979b) using normalized quantitative data was also used to arrange streams and water chemistry variables in an objective order along axes so that chemically similar streams occurred close together in ordination space. The strengths of axes were measured as eigenvalues, and the relative importance of each axis in explaining the variation in the data set was expressed as its eigenvalue divided by the sum of the eigenvalues for the three axes produced by the software (Weatherley & Omerod 1987). Positions of streams on the DECORANA axes were correlated with water chemistry and geological variables (see Table 4.5) using Pearson's correlation coefficient.

Cluster analysis and DECORANA were performed using the PC-ORD software package (McCune 1991).

Results

Comparisons of individual water chemistry variables for each ecoregion are given in Figures 4.1 to 4.4, and statistical comparisons among ecoregions are provided in Table 4.2.

The pH of streams in most ecoregions was close to neutral (range 6.2-8.1) although some of those in the Westland ecoregion were more acidic (range 4.7-7.5)(Fig 4.1, Table 4.2). Conductivity values were generally higher in east coast ecoregions than western ones, and were higher in the South-east Forest (160-237 μS cm^{-1}) than in all others except Banks Peninsula, and the East Coast Plains. Conversely, Southern Alps streams had lower conductivities (5-88 μS cm^{-1}) than streams in other regions except Westland and the Southland Plains. A single stream, Tussock Creek, in Southland had an abnormally high conductivity value (466 μS cm^{-1})(Fig. 4.1) possibly resulting from seepage from a nearby swamp. Alkalinity varied greatly among ecoregions with higher values recorded in North-east and

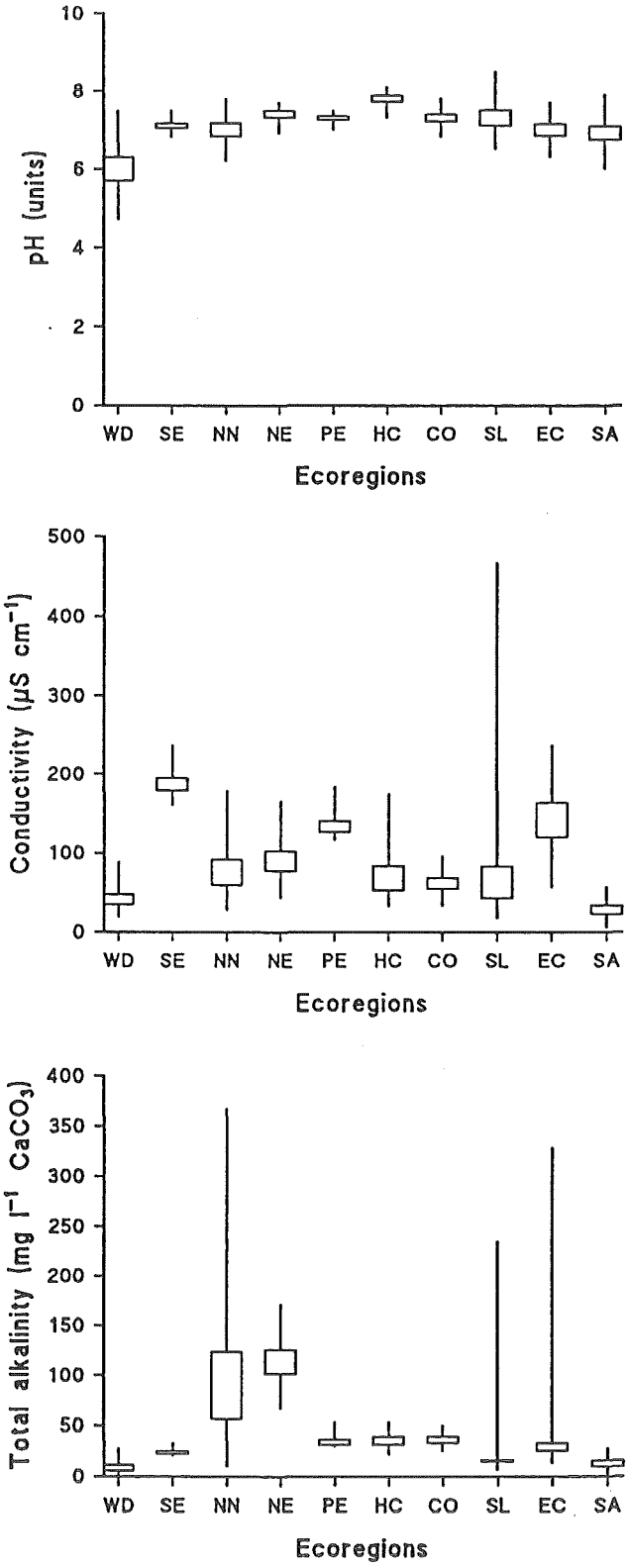


Figure 4.1 Box plots summarising pH, conductivity (at 25°C) and alkalinity values for each ecoregion. The boxes extend ±1SE above and below the mean; each whisker shows the maximum and minium values recorded within an ecoregion (n=10).

Table 4.2 Mean values for water chemistry variables obtained for the 10 streams in each ecoregion (±1SE). F and P values refer to parametric ANOVA statistics, unless otherwise stated.

	WD	SE	NN	NE	PE	HC	CO	SL	EC	SA	$F_{[9,99]}$	P
pH	6.0(0.3)	7.1(0.06)	6.9(0.2)	7.4(0.9)	7.2(0.05)	7.8(0.1)	7.3(0.09)	7.3(0.2)	6.9(0.2)	6.9(0.19)	5.99	<0.01[1]
Cond.	41.0(6.5)	187(7.7)	75.8(16.1)	90.2(12.5)	133.4(6.5)	68.3(15.1)	61.6(6.7)	63.1(20.1)	141.8(21.7)	28.4(5.1)	14.94	<0.01
Alk.	8.4(2.6)	23.6(1.5)	90.3(33.3)	113.6(11.8)	33.5(2.5)	34.9(3.8)	35.9(3.0)	14.9(0.9)	28.9(3.6)	12.2(2.9)	18.42	<0.01
Na	2.9(0.4)	32.3(1.7)	6.2(2.0)	6.8(0.5)	15.5(1.2)	5.2(0.6)	6.2(1.3)	20.7(3.7)	11.3(2.9)	2.4(1.2)	26.27	<0.01
K	0.9(0.2)	2.6(0.1)	0.6(0.1)	0.8(0.09)	0.9(0.05)	1.1(0.2)	1.1(0.3)	1.4(0.2)	1.8(0.3)	0.5(0.06)	9.56	<0.01
Ca	2.4(0.5)	3.7(0.1)	9.3(5.2)	2.6(0.2)	4.0(0.3)	10.8(1.4)	9.5(1.0)	20.7(11.1)	10.5(1.1)	6.6(1.3)	8.79	<0.01
Mg	0.6(0.1)	4.6(0.2)	2.0(0.4)	1.7(0.3)	2.1(0.1)	1.8(0.3)	1.7(0.2)	5.7(0.7)	3.0(0.7)	0.4(0.08)	23.97	<0.01
Fe	0.2(0.07)	0.2(0.07)	0.08(0.05)	0.02(0.005)	0.21(0.06)	0.12(0.03)	0.50(0.17)	0.54(0.14)	0.21(0.05)	0.002(0.002)	2.9	<0.01
Mn	0.001(0.001)	0.04(0.01)	0.005(0.008)	0.008(0.003)	0.004(0.004)	0.03(0.01)	0.004(0.003)	0.01(0.003)	0.003(0.001)	0.00(0.00)	11.61	<0.01[1]
Al	0.1(0.03)	0.04(0.01)	0.5(0.3)	0.02(0.005)	0.01(0.004)	0.005(0.002)	0.01(0.003)	0.01(0.003)	0.06(0.02)	0.004(0.002)	2.13	<0.05[1]
Cl	4.3(1.4)	55.7(3.4)	53.6(1.5)	14.7(2.9)	27.9(3.2)	7.9(2.2)	10.6(0.9)	26.8(7.0)	13.1(3.5)	1.6(0.5)	21.66	<0.01
SO_4	0.4(0.1)	3.3(0.1)	2.5(0.6)	3.8(0.7)	1.4(0.3)	2.0(0.2)	1.6(0.2)	2.9(0.04)	1.36(0.23)	1.75(0.27)	11.74	<0.01
NO_3-N	0.07(0.02)	0.36(0.2)	0.14(0.06)	1.07(0.31)	0.26(0.07)	0.02(0.01)	0.08(0.03)	0.09(0.04)	2.78(0.19)	0.009(0.007)	14.27	<0.01
PO_4-P	0.01(0.004)	0.07(0.07)	0.03(0.01)	0.00(0.00)	0.34(0.30)	0.07(0.05)	0.04(0.03)	0.00 (0.00)	0.20(0.18)	0.008(0.008)	2.04	n.s.[1]

[1] results of non-parametric Kruskal-Wallis ANOVA.

Results of comparisons of means using Tukey's HSD test (P<0.05) following parametric ANOVAs. Ecoregion water chemistry variables which were significantly higher or lower than in other ecoregions are shown (+ = high values, - = low values).

Ecoregion	pH	Cond	Alk	Na	K	Ca	Mg	Fe	Mn	Al	Cl	SO_4	NO_3-N	PO_4-P
WD	N/A[1]	-		-		-	-		N/A[1]	N/A[1]		-	-	N/A[1]
SE		+		+	+		+				+			
NN			+					-			+			
NE			+					-						
PE		+												
HC								-					-	
CO								+						
SL		-					+	+						
EC		+			+								+	
SA		-		-			-	-			-		-	

[1] N/A= not applicable, variables tested by non-parametric Kruskal-Wallis ANOVA.

North-west Nelson ($\bar{x}$= 100 mg l^{-1} $CaCO_3$) (Fig. 4.1) than elsewhere. Mt.Peel Creek, in North-west Nelson also had an exceptionally high total alkalinity value (368 mg l^{-1} $CaCO_3$). The lowest alkalinities ($\bar{x}$<15 mg l^{-1}) were recorded in Westland, Southland and Southern Alp streams (Fig. 4.1).

Concentrations of the major cations were also highly variable, although they tended to be higher in the southern ecoregions and lowest in the west. Sodium concentrations were greatest in the South-east Forest streams (24-44 mg l^{-1}), whereas the lowest values were recorded in Southern Alps and Westland streams (ranges 0.53-13.25 and 1.63-6.14 mg l^{-1}, respectively)(Fig 4.2)(Table 4.2). Potassium concentrations were also higher in the South-east Forest ecoregion than in all other regions except the East Coast Plains (Fig. 4.2). Calcium concentrations were highest in streams of the Southland Plains, and lowest in Westland (Fig. 4.2). Similarly, magnesium concentrations were higher in Southland (2.7-8.4 mg l^{-1}) than in all other regions (0.08-6.5 mg l^{-1}) except the South-east Forest. Westland and Southern Alps streams had the lowest magnesium concentrations (0.43-1.89 and 0.08-2.75 mg l^{-1}, respectively)(Fig. 4.2).

Southland and Central Otago streams had the highest iron concentrations (up to 1.61 mg l^{-1}) whereas those in High Country (HC), North-west Nelson, North-east Nelson, and Southern Alps streams were significantly lower (range 0-0.45mg l^{-1})(Fig. 4.3). Manganese concentrations were highest in South-east Forest streams (0.01-0.16 mg l^{-1}), whereas in Southern Alps, Banks Peninsula and Westland streams manganese was barely dectectable (Fig. 4.3). The highest total aluminium values were recorded in streams of North-west Nelson, Westland, East Coast Plains and South-east Forest (Fig. 4.3).

Anion values also tended to be higher in the east than in the west of the South Island. Chloride concentrations were higher in South-east Forest (43.9-84.2 mg l^{-1}) and North-west Nelson streams (7.8-58.1 mg l^{-1}) than in all other ecoregions except Banks Peninsula, and they were lowest in the Southern Alps (0.44-4.42 mg l^{-1})(Fig. 4.4). Nitrate-N was barely

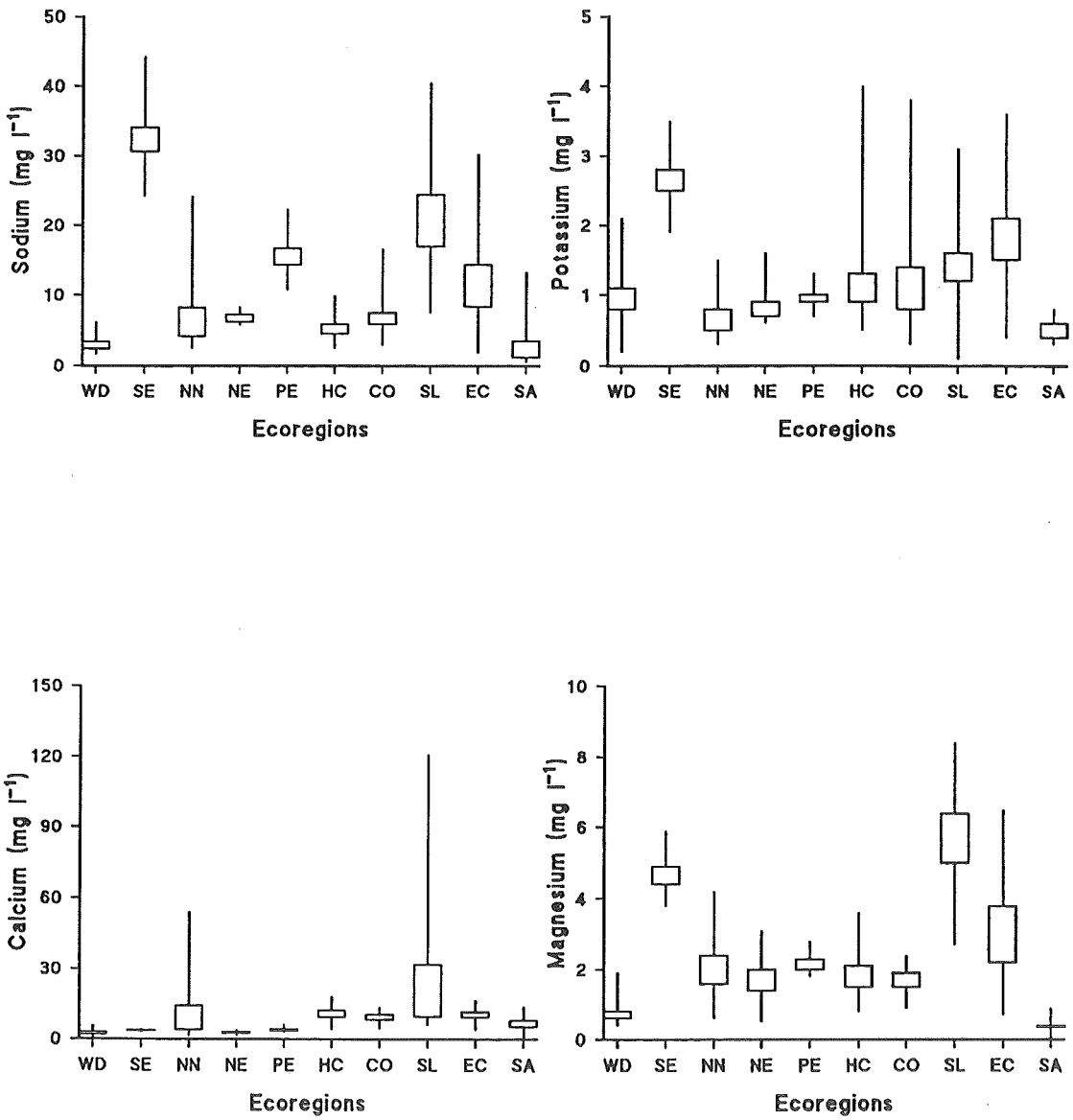


Figure 4.2 Box plots indicating major cation concentrations in streams in each ecoregion. The box extends ±1SE above and below the mean; each whisker shows the maximum and minium values recorded within an ecoregion (n=10).

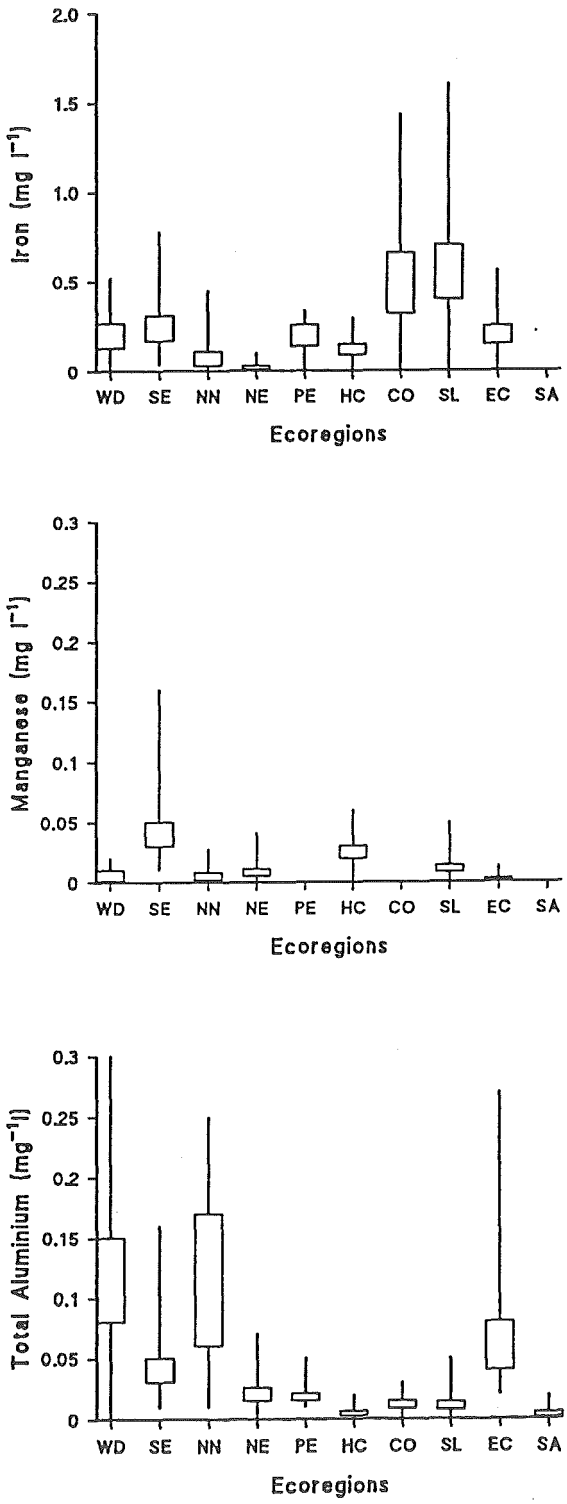


Figure 4.3 Box plots for iron, manganese and total aluminium for streams in for each ecoregion. The box extends ±1SE above and below the mean; each whisker shows the maximum and minium values recorded within an ecoregion (n=10).

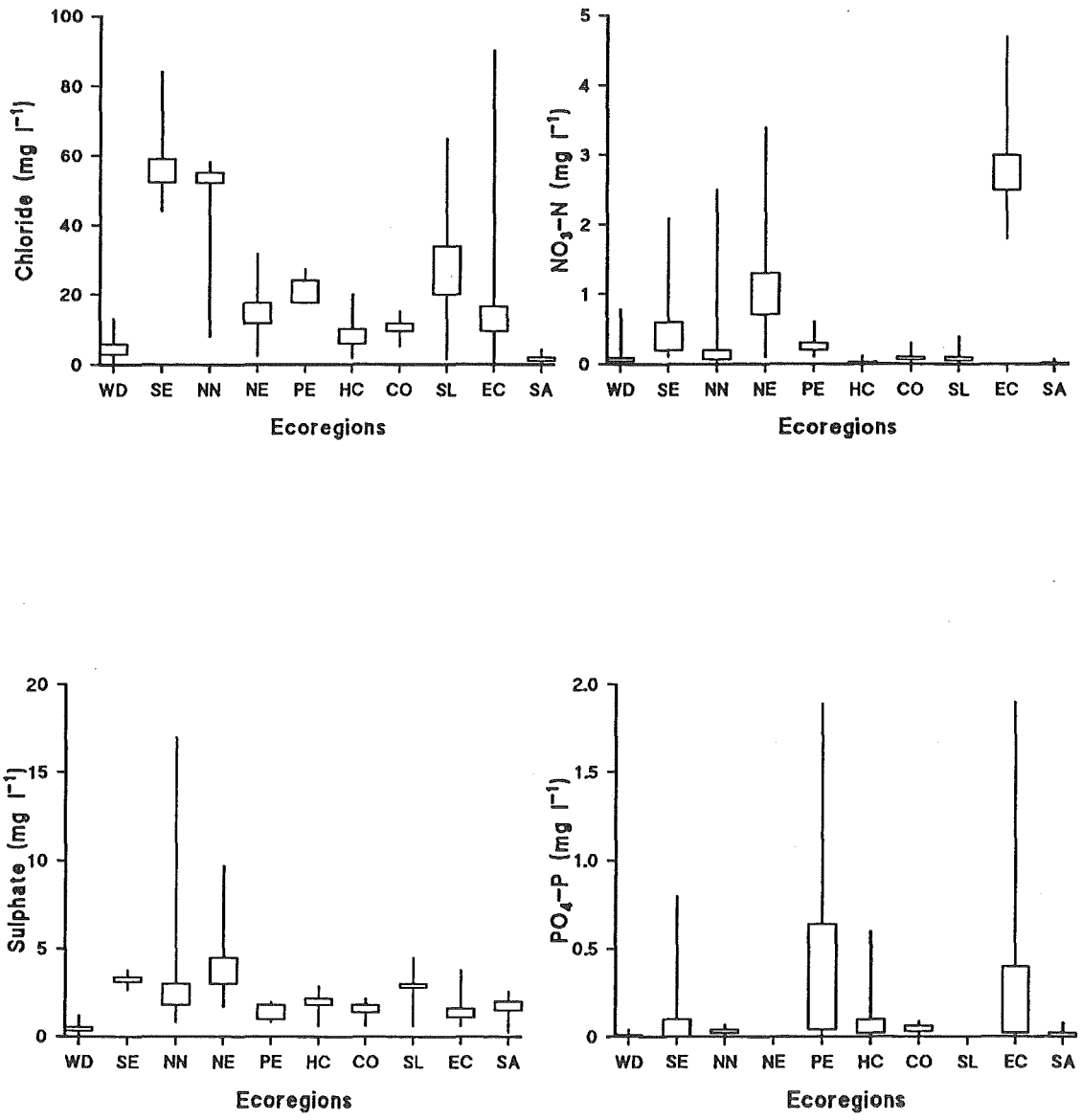


Figure 4.4 Box plots for the major anions for streams in each ecoregion. The box extends ±1SE above and below the mean; each whisker shows the maximum and minium values recorded within an ecoregion (n=10).

detected in Westland, High Country and Southern Alps ecoregions, and was highest in the East Coast Plains ecoregion (Fig. 4.4). Westland streams also had lower sulphate concentrations than those of all other ecoregions, but no differences in PO_4-P concentrations were found between regions.

Regional patterns

Stiff diagrams depicting concentrations of major cations and anions showed varying degrees of regional distinctness (Fig. 4.5). Westland, and the East Coast Plains ecoregions had high sodium/potassium: calcium ratios and low chloride values. In contrast, North-east Nelson and Banks Peninsula stream waters were dominated by chloride ions but also had high sodium/potassium: calcium ratios. The South-east Forest ecoregion, was distinguished from all other ecoregions by having streams dominated by sodium, potassium and chloride, and having low calcium: magnesium ratios. In contrast, the distinctive features of North-west Nelson streams were the predominance of chloride ions, and high calcium: sodium/potassium ratios. The remaining four ecoregions; High Country, Central Otago, Southland Plains, and the Southern Alps were all calcium-dominated streams, with high calcium: sodium/potassium ratios.

Cluster analysis of the 100 streams based on the combined, normalised water quality variables produced eight major clusters (Fig. 4.6). The two most similar clusters (5 & 6) contained most of the Central Otago and High Country streams, nine streams from Banks Peninsula and several streams from the Southland Plains and Central Otago. The main features they had in common were moderately high conductivities, and high calcium concentrations. The next most similar cluster (4) consisted of six Southern Alps streams, five Westland streams and several streams from Central Otago, Southland and the High Country. They had lower conductivities and calcium concentrations, and very low magnesium and chloride values (Table 4.3). High nitrate-N levels (1.8-2.7 mg l^{-1}) were characteristic of East Coast Plains streams (Cluster 3) which made up most of the next group to join this cluster.

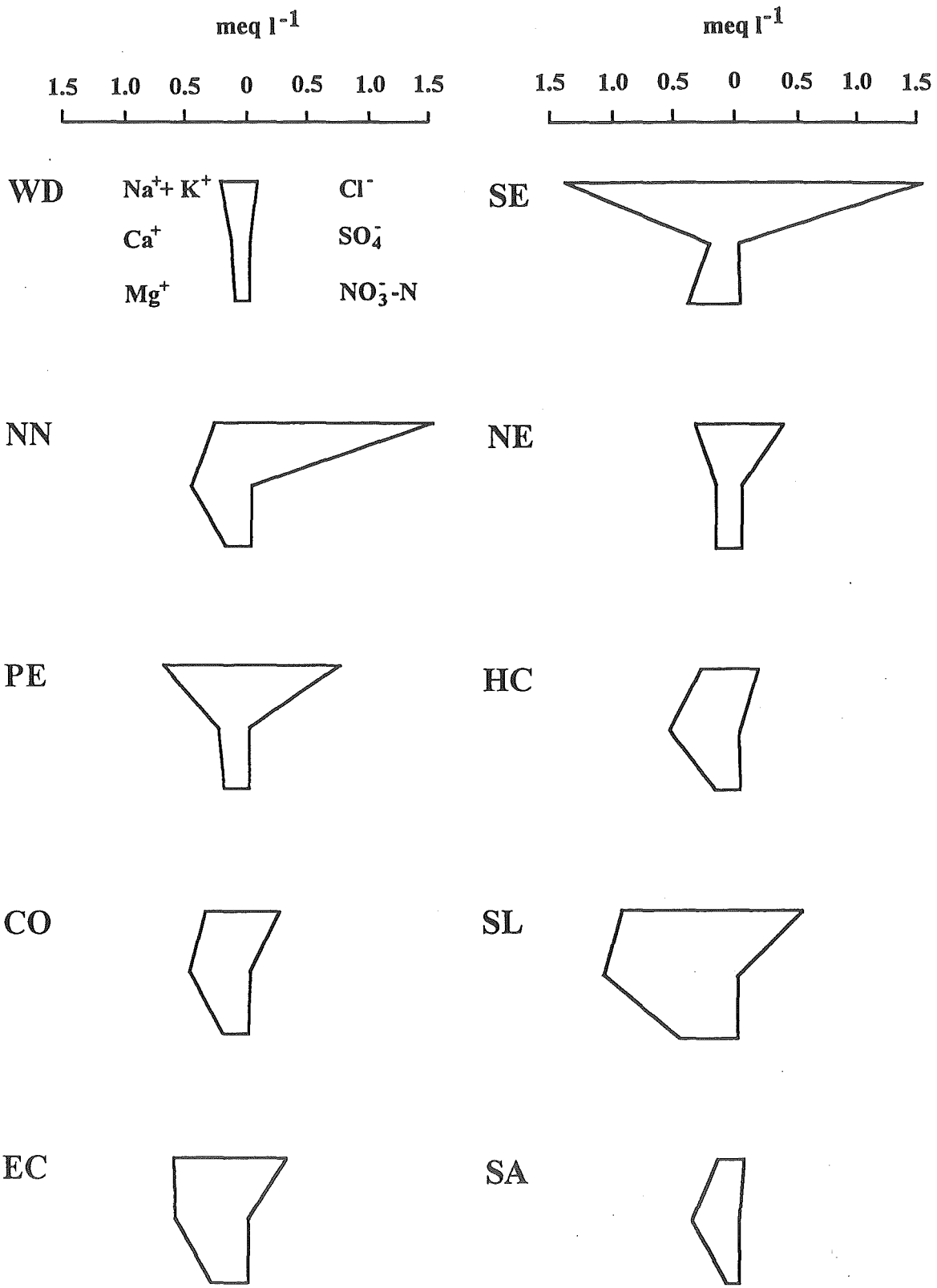


Figure 4.5 Stiff diagrams for each ecoregion showing mean values for major cations and anions in milliequivalents per litre (n=10).

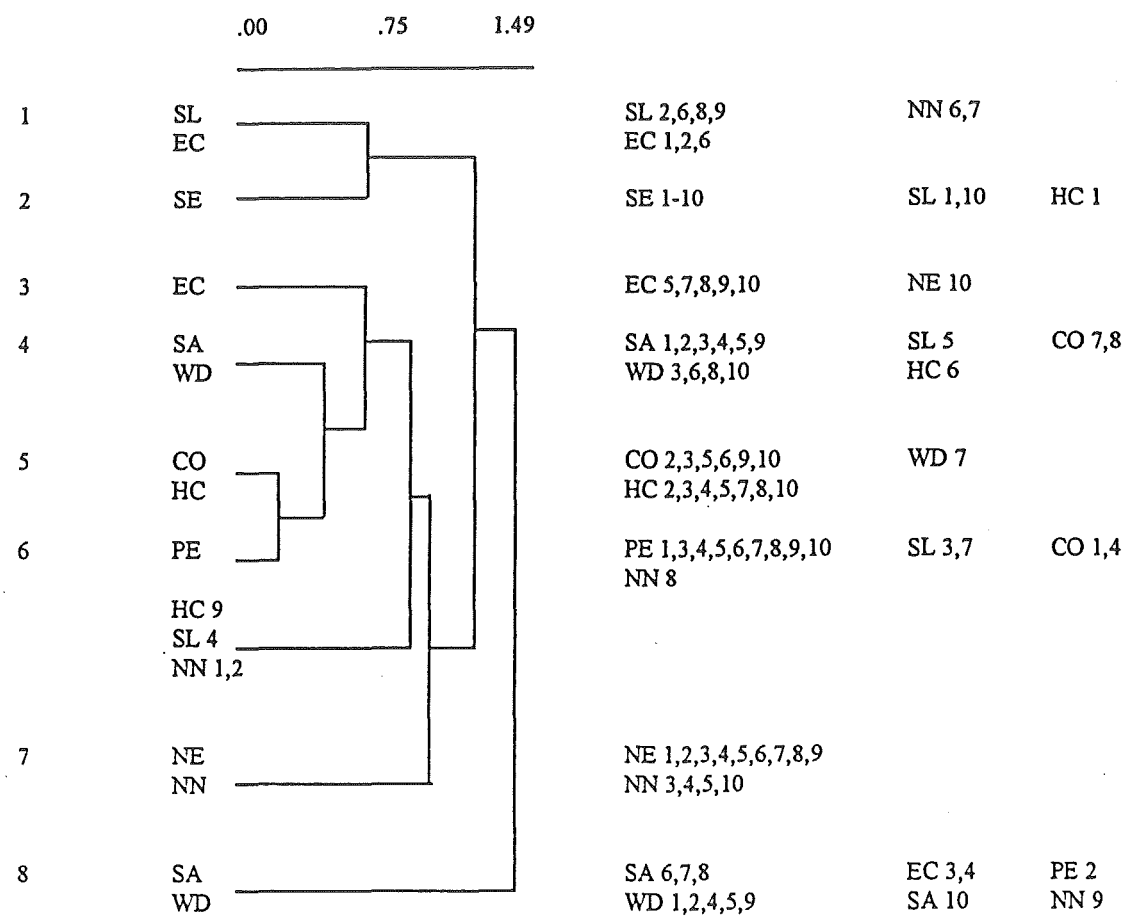


Figure 4.6 Cluster analysis of water chemistry variables for the 100 streams (distances are group average units).

Table 4.3 Mean values of chemical variables for the 8 stream clusters recognised by cluster analysis. Statistically significant (ANOVA; $P < 0.01$) values of a variable are shown in bold type.

Cluster	pH	Cond.	Alk.	Na	K	Ca	Mg	Fe	Mn	Al	Cl	SO_4	NO_3-N	PO_4-P
1	7.1	116	23	22	2.1	11.4	5.4	0.4	0.001	0.01	28.6	2.8	1.5	0.00
2	7.1	181	24	31	2.6	3.8	4.5	0.26	0.004	0.04	52.5	3.2	0.4	0.00
3	7.2	81	20	3.5	0.9	9.9	1.2	0.25	0.003	0.11	5.3	1.4	2.4	0.03
4	6.9	41	14	2.1	0.8	6.6	0.5	0.13	0.001	0.01	2.4	1.6	0.05	0.01
5	7.6	73	38	5.5	0.9	10.3	1.9	0.29	0.014	0.01	10.1	1.8	0.05	0.02
6	7.2	135	34	16	0.9	4.1	2.2	0.21	0.004	0.02	27.9	1.9	0.28	0.003
7	7.4	82	111	5.9	0.8	3.9	1.8	0.13	0.006	0.09	27.7	3.1	0.62	0.01
8	6.2	17	3.1	1.3	0.5	2.0	0.3	0.04	0.000	0.06	1.3	0.4	0.02	0.00

Most of the North-east Nelson streams and four North-west Nelson streams formed the next group (7) which had the highest alkalinities of any cluster (72.6-171 mg l^{-1} $CaCO_3$). Clusters 1 and 2 were clearly distinguished from those already discussed and consisted of several streams in two intensively farmed ecoregions, East Coast Plains and the Southland Plains, two streams in North-west Nelson, and all the streams in the South-east Forest ecoregion. These streams were characterised by generally high ion concentrations, and therefore conductivities (Table 4.3). The chemically most distinct group of streams made up Cluster 8 and comprised five Westland streams, three Southern Alps streams and five streams four other regions. Cluster 8 streams had the lowest mean pH and lowest total ionic concentrations (mean conductivity 17 μS cm^{-1}) of all 8 groups (Table 4.3).

Detrended correspondence analysis did not clearly separate streams on an ecoregion basis on Axes 1, 2 or 3, although streams from individual ecoregions were generally grouped together (Fig. 4.7). DECORANA eigenvalues indicated that Axis 1 accounted for 62%, axis 2 for 29% and Axis 3 for 9% of the total variance explained by the three axes. The first DECORANA axis was positively correlated with conductivity, nitrate-N concentrations, and the percentage of the catchment with alluvial soils (%ALLUVIUM) (Table 4.4). Axis 2 was positively correlated with PO_4-P concentration, alkalinity, total aluminium concentration, and the proportion of catchment in soft sedimentary bedrock (%SOFTSED) and negatively correlated with conductivity, and the concentrations of sodium, magnesium, potassium, chloride, and sulphate. Axis 3 was positively correlated with a wide range of water quality variables including aluminium, alkalinity, phosphate-P, conductivity, iron, potassium, magnesium, acidity, manganese, sodium, nitrate-N, and proportion of the catchment in loess soils (Table 4.4).

The proportions of major geological and soil types in a catchment were also correlated with individual water chemistry variables (Table 4.5). Thus, the percentage of soft sedimentary rocks was highly correlated with sodium, potassium, chloride, iron, magnesium and manganese concentrations. In contrast, the percentage of alluvium was strongly and

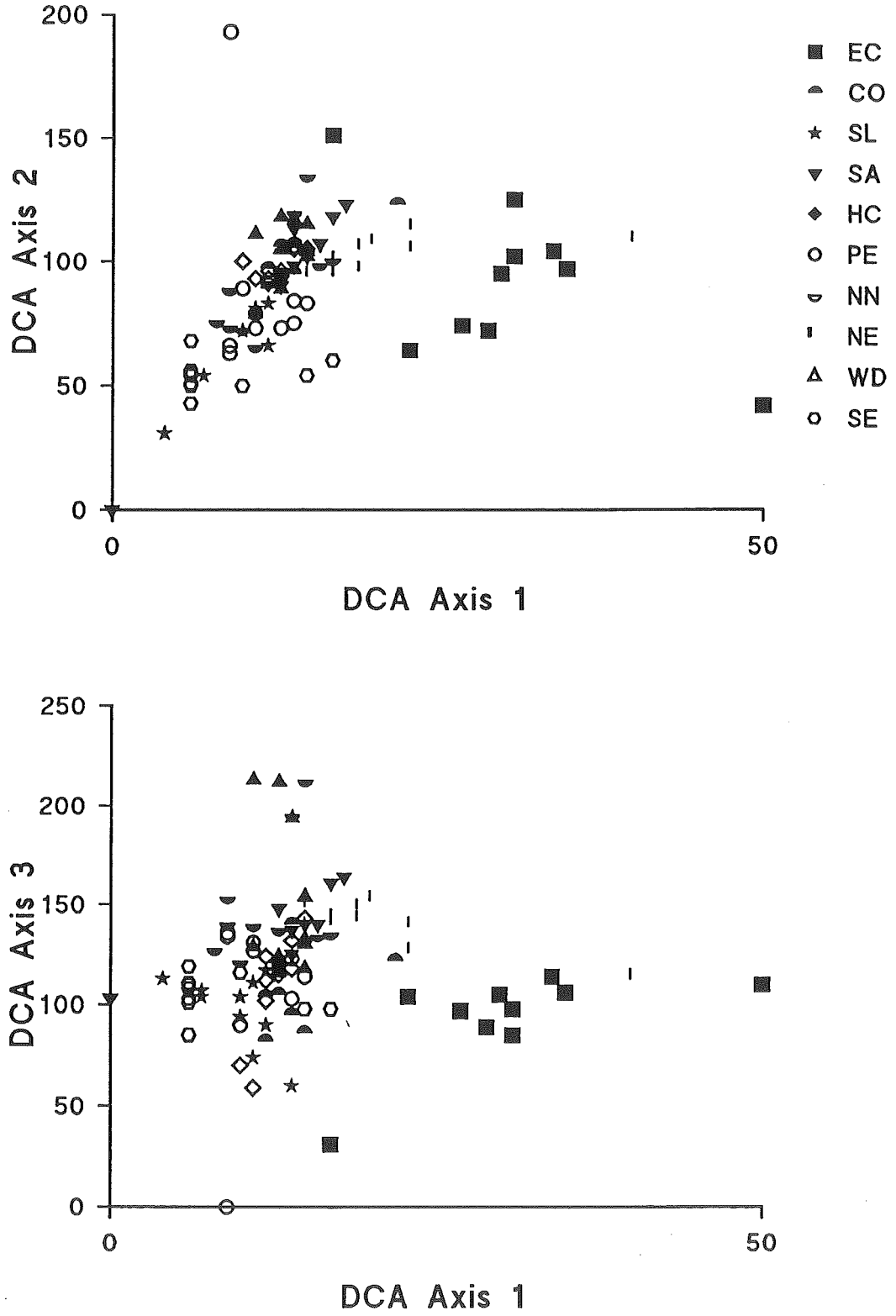


Figure 4.7 Ordination of 100 streams in the 10 ecoregions by DECORANA on the basis of standardised water chemistry variables (see Text). Upper axes 1 and 2, lower axes 1 and 3.

Table 4.4 Pearson's correlation coefficients for DECORANA axes and water chemistry and catchment geology variables for the 100 streams (P <0.01**, P <0.05*).

	Axis1	Axis 2	Axis 3
pH	-0.07	-0.05	-0.36**
Conductivity	0.21*	-0.36**	-0.29**
Alkalinity	0.05	0.22**	0.29**
Na	-0.04	-0.65**	-0.37**
K	0.13	-0.48**	-0.44**
Ca	0.01	0.03	-0.15
Mg	0.12	-0.49**	-0.37**
Fe	-0.02	-0.08	-0.43**
Mn	-0.08	-0.15	-0.26**
Al	-0.01	0.21*	0.39**
Cl	-0.12	-0.43**	-0.05
SO_4	-0.13	-0.33**	-0.14
NO_3-N	0.53**	-0.02	-0.22**
PO_4-P	-0.04	0.47**	-0.50**
%ALLUVIUM	0.29**	0.09	-0.14
%HARDSED	-0.07	0.08	0.19
%VOLC	-0.06	0.00	-0.04
%LOESS	0.19	-0.15	-0.40**
%SCHIST	-0.02	0.12	-0.06
%SOFTSED	-0.16	-0.28**	-0.15

Table 4.5 Pearson's correlation coefficients for the major catchment geology types and water chemistry variables for the 100 streams surveyed (P<0.01**,P<0.05*). Cations and anions not significantly correlated with any geological type are not included.

	pH	Cond.	Alk.	Na	K	Mg	Fe	Mn	Cl	NO_3-N	PO_4-P
%ALLUVIUM	-0.19*	0.08	-0.10	-0.07	0.15	0.14	0.25*	-0.19	-0.33**	0.53**	0.00
%HARDSED	0.02	-0.14	0.16	-0.16	-0.19*	-0.17	-0.11	-0.13	-0.08	-0.15	-0.03
%SOFTSED	-0.05	0.15	-0.18	0.42**	0.37**	0.21*	0.26*	0.21*	0.34**	-0.24*	-0.02
%SCHIST	0.08	-0.15	-0.03	-0.14	-0.03	-0.12	-0.07	0.15	-0.15	-0.09	-0.03
%LOESS	0.11	0.45**	-0.20	0.27**	0.13	0.39**	0.20*	-0.14	0.01	0.38**	0.17
%VOLC	0.01	0.10	-0.06	0.11	-0.10	-0.06	-0.06	-0.15	0.07	-0.08	0.23*

positively correlated with nitrate-N and iron concentrations, and negatively correlated with pH and chloride. Hard sedimentary bedrocks were associated with low potassium concentrations, whereas catchments with loess soils were positively correlated with conductivity, magnesium, nitrate-N and iron. A significant negative correlation was found between the percentage of volcanic bedrock and PO_4-P concentration.

Discussion

Considerable variability was recorded in the water chemistry of the 100 streams considered in this study. Generally, anion and cation concentrations were lower in the west of the South Island and higher in the east, however, water chemistry conditions varied markedly between streams within ecoregions. Nevertheless, several ecoregions did have streams with well defined chemical properties, in particular, this was true of the South-east Forest, and North-east Nelson ecoregions. Conversely, streams in the Southland Plains, East Coast Plains and North-west Nelson were much less distinctive, and when viewed across the full spectrum of chemical species were highly variable.

Streams within the South-east Forest ecoregion had amongst the highest conductivity levels of streams in any ecoregion, a consequence of their high sodium, potassium, magnesium, chloride and sulphate levels. The high values of these five ions and low calcium:magnesium ratios distinguished the streams in this ecoregion from all others in the study. It also made them contrast strongly with "average" New Zealand rivers which are characterised by equal proportions of calcium and sodium (Close & Davies-Colley 1990a). The high sodium and chloride concentrations of the South-east Forest streams may have been derived from the soft sedimentary sandstone and mudstone bedrock which is abundant in their catchments. Close & Davies-Colley (1990b) also found that streams in catchments with high proportions of soft sedimentary bedrock had the highest mean conductivities (271-471 μS cm^{-1}), calcium ($\bar{x}$=8.3 mg l^{-3}) and magnesium ($\bar{x}$=1.5 mg l^{-3}) concentrations observed in their nationwide survey of 96 rivers, values within the ranges of those recorded in my

South-east Forest ecoregion streams. Sodium and chloride concentrations could also have been elevated by the addition of salt deposits as dry fallout (Likens et al. 1977, Martin & Harris 1982), and Chadderton (1990) suggested that high conductivities (up to 975 μS cm^{-1}) recorded in coastal freshwater streams of Stewart Island (part of the South-east Forest ecoregion), were influenced by salt spray blown inland by strong, prevailing sea breezes.

Nine of the 10 streams sampled within the North-east Nelson ecoregion were also grouped together in the cluster analysis. They had high alkalinities, and low iron concentrations, and demonstrated a high overall degree of uniformity in water chemistry. This was despite considerable variation in geology within the region with different catchments being dominated by greywacke, granite, gneiss, and sandstone. In contrast, both Westland and Southern Alps streams had very low dissolved ion concentrations. Many Westland streams are acidic (Collier & Winterbourn 1987, Winterbourn & Collier 1987, Collier et al. 1989, Winterbourn & Ryan 1994), their acidity resulting primarily from high concentrations of humic and fulvic acids derived from decomposing organic matter in podzolic soils. Total aluminium and iron concentrations were comparatively high, and calcium levels were low, as is typical of many acid waters elsewhere (Drever 1982, Bache 1983, Stenzel & Herrmann 1990). Similar findings were reported by Winterbourn & Collier (1987) and Stenzel & Herrmann (1990) in extensive surveys of streams on the West Coast of the South Island. Mosley & Rowe (1981) also recorded low sodium, calcium, magnesium, potassium, phosphate and nitrate concentrations similar to those recorded in this study, in forested streams near Reefton and in coastal Westland.

Streams in the Southern Alps included those with the lowest conductivities, sodium, chloride, magnesium and sulphate concentrations. Their "dilute" chemical nature is a consequence of the high rainfall of the region, combined with high and rapid runoff exacerbated by thin soils and steep slopes. Furthermore, the greywacke substrate characteristic of the Southern Alps is generally poor in ions, and weathers relatively slowly. My findings are consistent with those of Stenzel & Herrmann (1990) who also recorded low conductivities

(13-46 μS cm^{-1}) in several Southern Alpine streams.

Streams on volcanic Banks Peninsula (PE) were distinguished by their high conductivities (116-184 μS cm^{-1}) which were associated with above average sodium and chloride concentrations. Similar conductivities (147-196 μS cm^{-1}) have been reported for other streams on the peninsula (Stenzel & Herrmann 1990) and like the coastal streams of Stewart Island they are probably influenced by on-shore winds that transport salt inland. High phosphate-P concentrations ($\bar{x}$ 0.34 mg l^{-1}) were also characteristic of the Banks Peninsula streams and is consistent with findings of Timperley (1983) and Close & Davies-Colley (1990b) that volcanically derived catchments and high phosphorus concentrations are often correlated.

Finally, streams within the East Coast Plains ecoregion had higher than average conductivities, potassium and nitrate-N concentrations, and were undoubtedly influenced by agricultural and urban land use activities. High nitrate-N and potassium concentrations have been widely reported in waterways in arable, pastoral and urban land (McColl et al. 1977, Bargh 1978, Currie & Gilliland 1980, McColl & Syers 1981, Taranaki Catchment Commission 1984, Wilcock 1986).

In summary, it is apparent that several ecoregions contained streams that differed considerably across the spectrum of chemical conditions sampled, and no ecoregions were separated completely by cluster analysis or DECORANA. However, a majority of the streams within the South-east Forest, Banks Peninsula, North-east Nelson, Central Otago and High Country ecoregions were clustered on an ecoregional basis. The results of this survey of water chemistry variables in 100 streams therefore indicated that streams within most ecoregions had some chemical conditions in common, although the overall chemical profiles of streams within ecoregions were sometimes very different. My findings concur with those of Close & Davies-Colley (1990a,b) who found that the larger rivers considered in their study could be characterised by a limited number of chemical conditions. Catchment level differences in geology, soils, vegetation, rainfall and catchment slope, ensure that the

water chemistry of streams within an ecoregion is not uniform. My findings support the view that differences in the geology of catchments, in particular the presence or absence of alluvium, mudstone, soft sedimentary rocks, and volcanic rocks have particularly important influences on the water chemistry of individual South Island streams.

Chapter 5

A comparison of streams in catchments with contrasting land use in a single ecoregion

Introduction

Results presented in Chapters 3 and 4 indicate that links exist between the macro-environmental factors that delineate ecoregions, and the water chemistry and benthic faunas of streams within ecoregions. However, the relative importance of each of these primary variables (vegetation and land use, relief, geology, and climate) is unclear. The findings presented in Chapter 3 indicate that the macroinvertebrate fauna of streams in the three anthropogenically modified ecoregions of the Southland Plains, Central Otago and East Coast Plains were so similar as to be indistinguishable on ecoregional grounds. This implies that, under certain circumstances, the effects of vegetation and land use can be more important than the combined influences of climate, relief, soils, and bedrock geology, on the structure of benthic communities.

The influence of different land use activities on water quality and benthic communities has been investigated in several parts of New Zealand. Emphasis has been primarily on the effects of pollution and eutrophication (Hirsch 1958, Suckling 1982), channelisation (Quinn et al. 1992, Williamson et al. 1992) and forestry practices (Graynoth 1979, Rounick & Winterbourn 1982, Cowie 1985, Winterbourn 1986, Pruden et al. 1990, Taranaki Reginal Council 1991). Few New Zealand studies have compared the effects of different land practices (Quinn & Hickey 1990, Scott et al. 1994, Quinn et al. in press). The few studies that have done so, have noted consistent reductions in taxonomic richness in streams draining arable land compared with streams in less developed catchments, and the replacement of enrichment-sensitive taxa (certain Plecoptera, predatory Trichoptera, and Ephemeroptera)

with more tolerant taxa. These faunal changes have been linked indirectly to a suite of modified physico-chemical and biological conditions that occur in arable land streams, including elevated temperatures, nutrients and periphyton biomass, and increased flow variability (Quinn & Hickey 1990).

The primary aim of the work presented in this chapter was to investigate differences in the water chemistry, and benthic communities of streams draining catchments characterised by four differing land use types; pastoral, tussock and scrubland, exotic forest and native forest, within a single ecoregion. Having identified any differences caused by variations in land use activities and seasonal factors I wished to assess their effects on the discrimination of my lotic ecoregions, by addressing the question, "does the occurrence of different land use patterns within an ecoregion nessitate a modification of the classification ?"

Study area

The study was conducted in 16 small streams (first-third order) flowing into the Waiau River, near Hamner Springs, 120 km north west of Christchurch within the High Country ecoregion (Fig. 5.1). Four streams were selected in each of four land use categories; pastoral grassland, tussock-scrubland, exotic forest, and native forest. Streams were sampled four times (once per season) between December 1992 and November 1993. Pastoral streams were selected in lowland, intensively farmed catchments stocked with sheep and vegetated in clover and pasture grasses. These streams were generally slow flowing, with streambeds dominated by cobbles and pebbles (Table 5.1). On several occasions water clarity was impaired by cloudy runoff, presumably caused by livestock (Fig. 5.2). The primary soil types in these catchments were stony soils on yellow-grey earths, although greywacke was the major underlying bedrock (NWASCO 1975). Scrub and tussock-covered catchments were sampled in low, hill country south-west of Hamner Springs, and were dominated by silver tussock (*Poa laevis*), hard tussock (*Festuca novae-zelandiae*), gorse (*Ulex europaeus*),

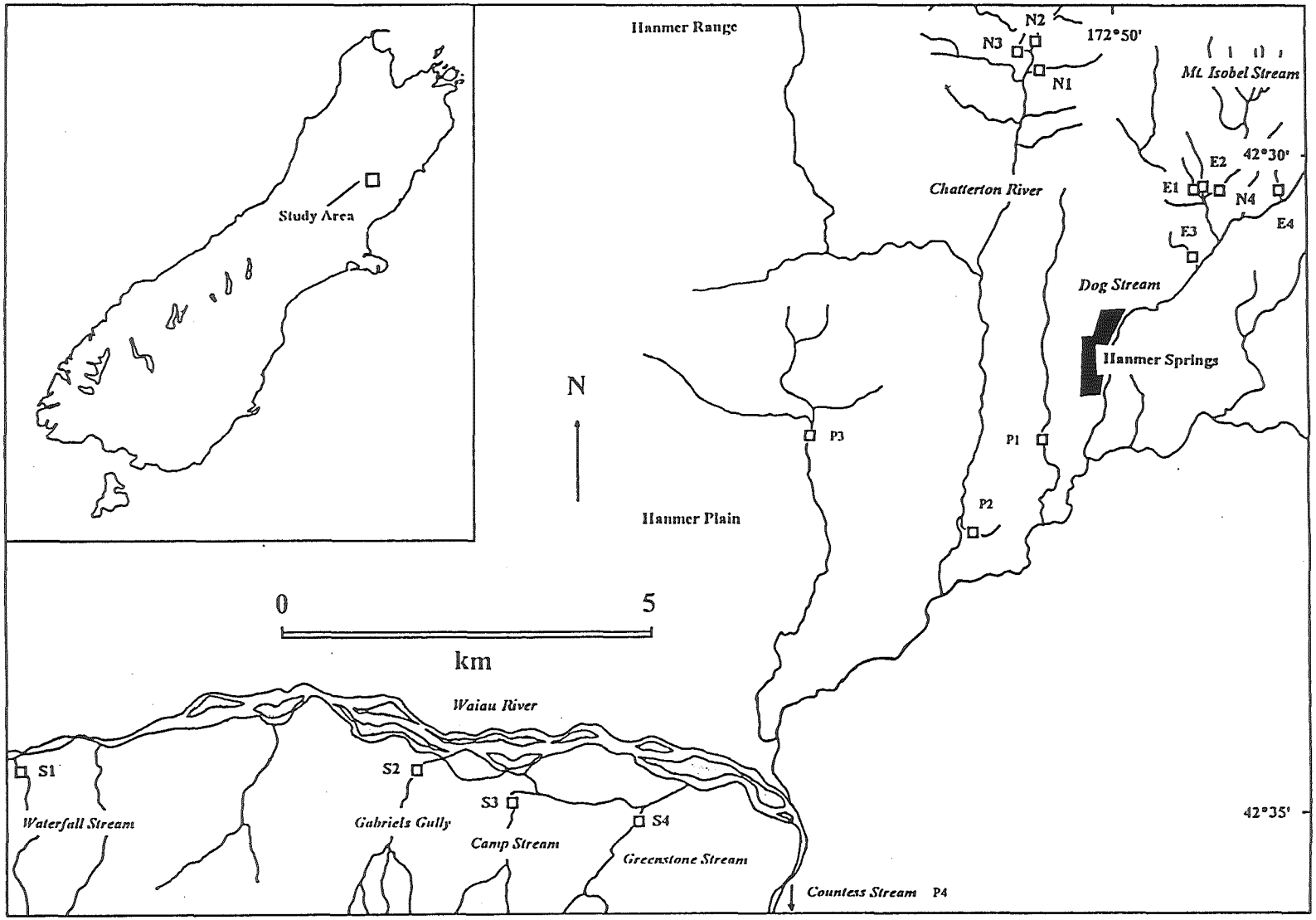


Figure 5.1 Map showing the 16 streams sampled near Hanmer Springs (P = pastoral streams, S = scrubland streams, E = exotic forested streams, N = native forested streams).

Table 5.1 Physical habitat conditions recorded for the streams with four types of land use (values are means of 4 streams x 4 seasons ± 1SE). *P* and *F* values refer to comparisons of land use group by one-way ANOVA.

	Pastoral	Scrubland	Exotic	Native	$F_{[3,64]}$	*P*
Elevation (m)	295 (32)	390 (26)	440 (14)	560 (38)	19.89	0.01
Width (m)	1.1 (0.08)	0.9 (0.06)	0.5 (0.04)	1.4 (0.15)	15.95	0.01
Depth (cm)	10.1(1.7)	11.8 (0.7)	6.6 (0.5)	10.6 (0.9)	6.01	0.01
Velocity (m s^{-1})	0.2 (0.2)	0.3 (0.2)	0.1 (0.07)	0.3 (0.1)	7.08	0.01
Substrate size (SI)	4.5 (0.1)	5.0 (0.1)	4.3 (0.1)	5.0 (0.1)	20.34	0.01
Spot temperature (°C)	11.5 (0.8)	9.0 (0.5)	7.3 (0.4)	6.9 (0.5)	10.33	0.01

broom (*Cytisus scoparius*), blackberry (*Rubus fruticosus*), and isolated stands of exotic trees (*Pinus radiata*). These streams were generally steep, and fast flowing with beds dominated by boulders and cobbles (Table 5.1, Fig. 5.2). The primary soil types in these catchments were yellow-grey earths. In contrast, streams in the exotic forested catchments were smaller, shallower, and slower flowing. The primary vegetation in these catchments was *Pinus radiata*, although the stream banks at several sites were covered in broom and blackberry. These exotic forest streams were characterised by numerous woody debris jams (mainly tree prunings, cones, and pine needles), whereas the substrate was dominated by cobbles, and gravels (Table 5.1, Fig. 5.3). Catchment soils in these and the native forest streams were mainly yellow-brown earths. The native forested catchments were mainly vegetated with beech (*Nothofagus* spp.), and had understoreys of ferns and broadleaf trees. Native forest streams were generally wider, and faster-flowing than those in exotic forest, and their substrata were dominated by boulders, and cobbles. Debris structures were rare in beech forest streams, although one stream (N3) had extensive mats of bryophytes present throughout the streambed, and these trapped leaves and small sticks (Table 5.1, Fig. 5.3).

Climatic data recorded at Hanmer Forest Park headquarters indicated that rainfall between October 1992 and December 1993 was 1538 mm (NIWA 1993). Maximum-minimum air temperatures were coolest in May-August, and warmest in November 1992-February 1993; rainfall was evenly spread throughout the year (Fig. 5.4).

Figure 5.2 a) A typical stream in a pastoral catchment (P1). Streambeds were exposed to direct sunlight, although grasses enroached on the stream. The stream channel was widened by stock in several places. Cobble and pebble substrates dominated. b) Gabriels Gully (S2) was typical of scrubland streams with broom, gorse, tussock, bracken and isolated exotic trees near the stream banks. Larger boulders were common in the streambed although cobbles dominated.

A

B

Figure 5.3 a) An exotic forested stream (E2) with numerous woody debris jams. Ferns and grasses covered the banks below exotic canopies. Streambeds had patches of bryophytes indicating stable substrata. b) Native forested streams (N3) had patches of direct sunlight reaching sections of reaches. Large boulders were present although the substrate was dominated by cobbles. Bryophyte mats were prolific.

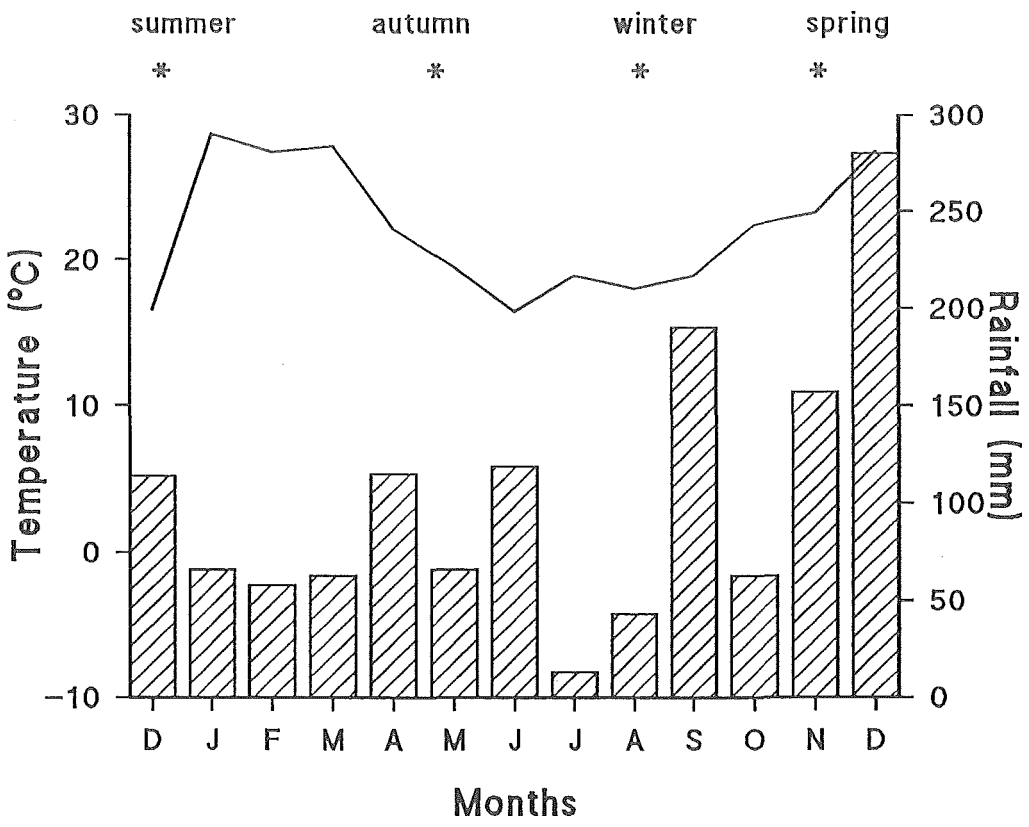


Figure 5.4 Maximum air temperature and total monthly rainfall measured at Hanmer Forest between December 1992 and December 1993 (NIWA 1993). Asterisks indicate the four sampling occasions.

Materials and methods

At each site, mean stream width, mean depth, mean current velocity, an index of substrate size (see Chapter 3 for calculation)(Jowett & Richardson 1990), and water temperature were recorded on each sampling occasion. Mean values were calculated from measurements taken at three locations along a 5 m reach. At the same locations, water and invertebrate samples were collected. Altitude was estimated from a 1: 50,000 topographical map (New Zealand Survey & Land 1989, NZ260 N32). An estimate of epilithic biomass was obtained for each stream by extracting photosynthetic pigments from five randomly collected cobbles (each approx 6 x 4 cm). The stones were soaked in 90% acetone for 12h at 5°C in the dark. Chlorophyll *a* and pheopigment were calculated using the method of Moss (1967a,b), and were summed to provide a measure of epilithic biomass.

Water samples were collected in 500 ml, opaque, polyethylene bottles, refrigerated, and returned to the laboratory within three days for analysis. Conductivity, pH, and alkalinity were measured by the procedures described in Chapter 4; autumn and summer sub-samples were also analysed for cations and anions as described in Chapter 4.

Five Surber samples (0.11 m^2; 0.25 mm mesh) were collected from riffles and runs in each reach, and preserved in 10% formalin in the field. Samples were sorted in the laboratory under 10X magnification. Larvae were identified using the keys listed in Chapter 3. Invertebrate biomass was estimated by air-drying samples from each Surber collection for a minimum of seven days in a 30°C cabinet, followed by ashing at 550°C for 4h. AFDW of organic matter was estimated by treating the wood, leaves, detritus and gravel from each Surber sample in a similar way. Organic matter from the spring samples was pooled to form a combined sample for each stream.

Statistical analysis

In order to investigate differences in land use patterns and seasonality, physical, chemical and invertebrate data were tested by ANOVA. Data were first tested for normality, and homoscedacity using Cochrane's Q test, and datasets with unequal variances were log or square root transformed. Physical habitat data were analysed using parametric one-way ANOVAs, or Kruskal-Wallis non-parametric ANOVA for data which could not be transformed, satisfactorily. Chemical and invertebrate data were analysed using two-way parametric ANOVA (or Friedman's non-parametric ANOVA for data that could not be transformed), and comparisons of means following a significant parametric ANOVA were conducted with Tukey's HSD test at the 0.05 level of significance (Sokal & Rohlf 1981, Analytical Software 1991).

Multivariate analysis was conducted using species presence/absence data to investigate patterns of taxonomic similarity among streams draining catchments differing in land use. Two techniques were used; two-way indicator species analysis (TWINSPAN) and

detrended correspondence analysis (DECORANA)(described in Chapter 3) to check that trends observed were not artifacts of analysis algorithms.

Results

Physico-chemical conditions and periphyton

Streams in the native forested catchments were wider and dominated by larger substrata than streams in other land use types (Table 5.1). Furthermore, water temperatures were consistently lower in native and exotic forested streams than in the open scrubland and pastoral streams regardless of season (Table 5.1). Similarly, AFDW of organic matter was significantly higher in both forested stream types than in scrub and pastoral streams, and the quantity of organic matter was lower in spring than in other seasons (Fig. 5.5, Table 5.2). In contrast, epilithic algal biomass did not differ significantly between land use types or between seasons (Fig. 5.5, Table 5.2).

Table 5.2 Statistically significant differences between land use groups, and seasons for total organic matter, epilithic algal biomass (chlorophyll *a*) and biotic parameters (Ps = pastoral, Sc = scrub. Ex = exotic forest, Na = native forest, Su = summer, Sp = spring, Wi = winter, Au = autumn; n = 16). *F* and *P* statistics refer two-way ANOVA results.

	Land use groups		Seasons	
	$F_{[3,64]}$	*P*	$F_{[3,64]}$	*P*
Total organic matter (AFDW g m^{-2})	40.3	0.01	33.3	0.01
Total chlorophyll *a* + pheopigment (μg cm^{-2})	0.35	n.s.	2.03	n.s.
Mean number of taxa	96.4	0.01	8.40	0.01
Invertebrate density (no. m^2)	114.4	0.01	5.13	0.01
Invertebrate biomass (DW g m^{-2})	162.9	0.01	8.40	0.01

Comparison of means between land use groups and between seasons using Tukey's HSD test ($P<0.05$) following two-way ANOVA. Significantly high and low land use groups and seasons are shown.

	Land-use groups		Seasons	
	High	Low	High	Low
Total organic matter	Ex, Na	Ps	Su, Wi, Au	Sp
Total chlorophyll *a* + pheopigment	n.s.		n.s.	
Mean number of taxa	Na	Ps	Su, Sp, Wi	Au
Invertebrate density	Ps, Sc	Ex	Wi, Sp	Au
Invertebrate biomass	Na	Ex	n.s.	

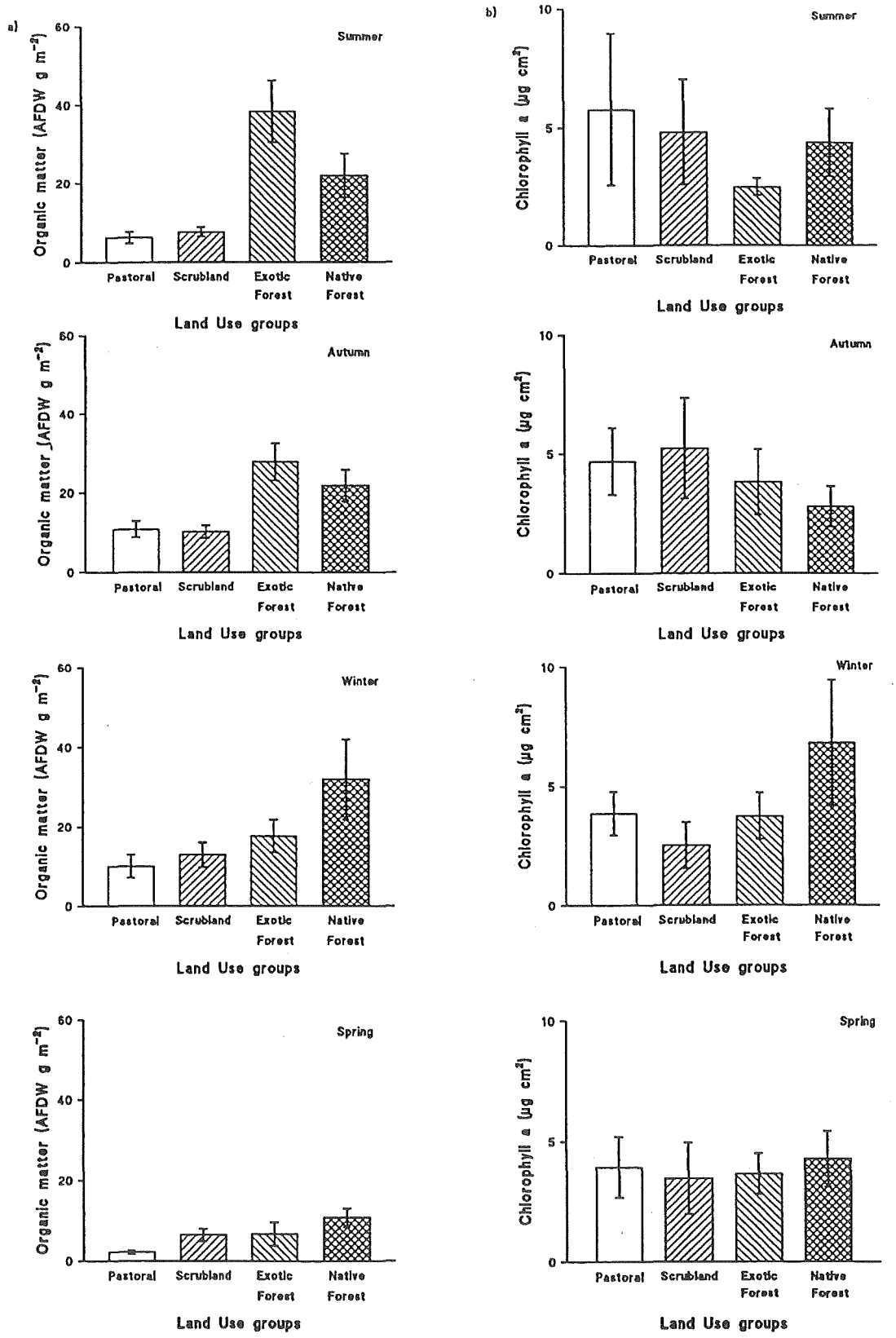


Figure 5.5 a) Mean organic matter standing stocks, and b) Chlorophyll + pheopigment concentrations in streams in each land use type (±1SE; n = 4). Summer, autumn, winter and spring values are shown.

Alkalinity, pH, calcium, iron, potassium, and magnesium concentrations differed significantly among the four groups of streams. The first three were higher in scrubland streams than the others, whereas iron and potassium concentrations were higher in pastoral streams (Table 5.3, 5.4). No significant differences associated with catchment type were distinguished for the other cations and anions measured. Alkalinity was the only water chemistry parameter that varied seasonally; significantly higher values were observed in autumn and winter than in summer and spring (Table 5.3, 5.4).

Macroinvertebrates

Macroinvertebrate faunas were taxonomically most diverse in the native forested streams where most species of Ephemeroptera, Plecoptera, Coleoptera, Diptera and Trichoptera were found. The mean number of taxa per stream was highest in native forest streams, and lowest in pastoral streams (Table 5.2). Mayfly, stonefly and caddisfly taxa were most poorly represented in pastoral streams (Table 5.5). In contrast, molluscan taxa were better represented in pastoral and exotic forest streams than in native forest and scrubland streams.

Invertebrate densities were higher in pastoral and scrubland streams than exotic forested streams, and peaked in numbers in autumn (Fig. 5.6, Table 5.2). Native forest streams had the highest, and exotic forest streams the lowest mean invertebrate biomass (Fig. 5.6, Table 5.2).

Ephemeropteran densities were significantly higher in scrubland streams than native and exotic forest streams, which in turn had higher densities than pastoral streams. Spring and winter densities were greater than those in summer and autumn (Fig. 5.7, Table 5.6). Plecopteran densities were highest in exotic forest streams (they were particularly high in summer), but were rarely collected in pastoral streams regardless of season (Fig. 5.7, Table 5.6). By comparison, the densities of trichopterans showed no seasonal trends and were highest in scrubland streams (Fig. 5.7, Table 5.6). Dipteran abundances were greatest in

Table 5.3 Results of chemical analyses on water samples taken in four streams in four land use types per season from streams in the High Country ecoregion near Hanmer Springs (mean values ± 1SE, - = not measured during this season). *F* and *P* statistics refer to ANOVAs comparing different land use groups and seasons. Cations and anions were measured on summer and autumn samples only.

	Pastoral				Scrubland				Land use	
	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	$F_{[3,32]}$	*P*
Alk (g $CaCO_3$)	31.5 (1.0)	42.2 (5.6)	46.0 (5.1)	16.7 (2.7)	60.7 (4.2)	62.5 (2.7)	58.5 (3.8)	20 (1.1)	35.15[1]	0.01
Ca (mgl^{-1})	6.2 (1.7)	3.2 (0.2)	-	-	16.6 (3.0)	15.5 (2.0)	-	-	68.72	0.01
Cl (mgl^{-1})	15.3 (7.0)	15.9 (0.9)	-	-	3.0 (0.8)	11.4 (3.8)	-	-	3.37	n.s.
Cond ($\mu S\ cm^{-1}$)	117.5 (47.8)	145.6 (66.6)	195.0 (94.9)	110.7 (12.5)	156.0 (10.9)	155.7 (9.0)	125.0 (7.33)	143.5(8.4)	2.34[1]	n.s.
Fe (mgl^{-1})	0.30 (0.18)	1.22 (0.39)	-	-	0.09 (0.06)	0.36 (0.14)	-	-	4.01	0.05
K (mgl^{-1})	1.39 (0.38)	1.05 (0.21)	-	-	0.77 (0.05)	0.96 (0.09)	-	-	6.14	0.05
Mg (mgl^{-1})	2.93 (0.53)	2.95 (0.36)	-	-	3.26 (0.38)	3.47 (0.41)	-	-	14.86	0.01
Mn (mgl^{-1})	0	0	-	-	0	0.01 (0.01)	-	-	0	n.s.
Na (mgl^{-1})	34.1 (20.4)	16.5 (7.6)	-	-	8.74 (2.78)	8.54 (2.09)	-	-	2.92	n.s.
NO_3-N(mgl^{-1})	0	2.52 (0.9)	-	-	0.71 (0.23)	0.46 (0.21)	-	-	1.72	n.s.
pH	7.2 (0.2)	7.3 (0.1)	7.4 (0.2)	7.2 (0.2)	8.0 (0.03)	7.5 (0.05)	7.5 (0.05)	7.5 (0.04)	15.42[1]	0.01
PO_4-P(mgl^{-1})	0	0	-	-	0.01 (0.01)	0.02 (0.01)	-	-	0	n.s.
SO_4(mgl^{-1})	3.4 (0.57)	3.86 (0.92)	-	-	5.62 (1.79)	3.84 (0.81)	-	-	0.23	n.s.
	Exotic forest				Native forest				Season	
	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	$F_{[3,32]}$	*P*
Alk (g $CaCO_3$)	31.7 (3.9)	39.7 (2.6)	46 (5.4)	14.5 (0.8)	20.0 (1.68)	25.5 (1.94)	27.2 (2.6)	32.2 (2.5)	18.27[1]	0.01
Ca (mgl^{-1})	9.6 (2.2)	7.3 (1.5)	-	-	5.5 (0.9)	4.4 (0.89)	-	-	8.83	n.s.
Cl (mgl^{-1})	6.8 (2.6)	10.9 (1.2)	-	-	4.6 (2.7)	10.3 (1.7)	-	-	4.73	n.s.
Cond ($\mu S\ cm^{-1}$)	99.0 (4.2)	73.7 (4.1)	103.1 (6.2)	120.3 (3.9)	68.2 (6.1)	45.2 (3.1)	61.7 (5.7)	76.5 (4.8)	0.35[1]	n.s.
Fe (mgl^{-1})	0.14 (0.08)	0.33 (0.14)	-	-	0.07 (0.05)	0.45 (0.29)	-	-	11.52	n.s.
K (mgl^{-1})	0.84 (0.25)	0.95 (0.07)	-	-	0.58 (0.03)	0.65 (0.04)	-	-	0.47	n.s.
Mg (mgl^{-1})	2.58 (0.25)	2.38 (0.19)	-	-	1.72 (0.14)	1.64 (0.19)	-	-	0	n.s.
Mn (mgl^{-1})	0	0	-	-	0	0	-	-	0	n.s.
Na (mgl^{-1})	4.28 (0.24)	4.15 (0.26)	-	-	3.19 (0.08)	3.18 (0.12)	-	-	0.56	n.s.
NO_3-N (mgl^{-1})	4.83 (1.83)	2.16 (0.96)	-	-	3.49 (2.46)	3.54 (1.21)	-	-	0.38	n.s.
pH	7.3 (0.1)	7.1 (0.05)	7.3 (0.08)	7.4 (0.07)	7.1 (0.2)	7.0 (0)	7.2 (0.1)	7.3 (0.04)	1.99[1]	n.s.
PO_4-P (mgl^{-1})	0	0	-	-	0	0	-	-	0	n.s.
SO_4 (mgl^{-1})	4.04 (0.71)	4.55 (0.75)	-	-	3.75 (1.42)	4.58 (1.08)	-	-	0	n.s.

[1] $F_{[3,64]}$

Table 5.4 Comparisons of means using Tukey's test following two-way ANOVA showing significantly higher and lower chemical variables in four different land use groups, and in four seasons (Ps = pastoral, Sc = scrub. Ex = exotic, Na = native, Su = summer, Sp = spring, Wi = winter, Au = autumn; n = 16). Cation and anion data that could not be analysed by parametric methods are excluded.

	Land use groups		Seasons	
	High	Low	High	Low
Alkalinity (g m^{-2} $CaCO_3$)	Sc	Ps, Na, Ex	Su, Sp	Wi, Au
pH	Sc	Ps, Na, Ex	n.s.	
Calcium (mg l^{-1})	Sc	Ex, Ps, Na	n.s.	
Iron (mg l^{-1})	Ps	Sc	n.s.	
Potassium (mg l^{-1})	Ps	Na	n.s.	
Magnesium (mg l^{-1})	Sc	Na	n.s.	

Table 5.5 Total number of taxa recorded in each stream in four seasons. The final column in each land use category indicates the total number of taxa recorded in that category.

	Pastoral					Scrubland					Exotic					Native				
	A1	A2	A3	A4	A	S1	S2	S3	S4	S	E1	E2	E3	E4	E	N1	N2	N3	N4	N
Ephemeroptera	1	1	3	1	3	2	3	5	3	6	4	3	4	2	4	7	5	4	6	8
Plecoptera	1	1	0	0	1	4	4	4	3	6	7	8	9	4	10	7	9	7	9	11
Megaloptera	0	0	0	0	0	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1
Coleoptera	0	1	1	1	1	1	1	2	1	2	2	2	2	2	4	3	5	2	2	5
Diptera	11	7	7	5	14	11	13	11	11	19	9	6	7	8	15	17	8	11	13	21
Trichoptera	9	8	9	11	13	17	15	14	13	27	12	11	10	9	18	16	16	13	12	21
Mollusca	4	4	4	5	5	1	1	1	2	2	3	4	3	4	3	1	2	2	3	2
Others	5	9	7	10	14	2	1	4	5	7	5	7	5	7	9	4	3	4	5	9
Total	31	31	31	33	51	39	39	42	39	70	43	41	40	36	64	56	49	44	51	78

pastoral and scrubland streams, and densities in all land use types were lowest in autumn (Fig. 5.8, Table 5.6). Significantly higher molluscan densities were recorded in pastoral streams than in other land use types (Fig. 5.8).

Community composition

Five "core taxa", *Deleatidium* spp., *Coloburiscus humeralis, Stenoperla prasina,* Elmidae and *Olinga feredayi* were collected on all sampling occasions in the native forest streams and together accounted for 55% of the total fauna in these streams (Table 5.7, Fig. 5.9). *Deleatidium* spp., *S. prasina* and *O. feredayi* were also common in exotic forested

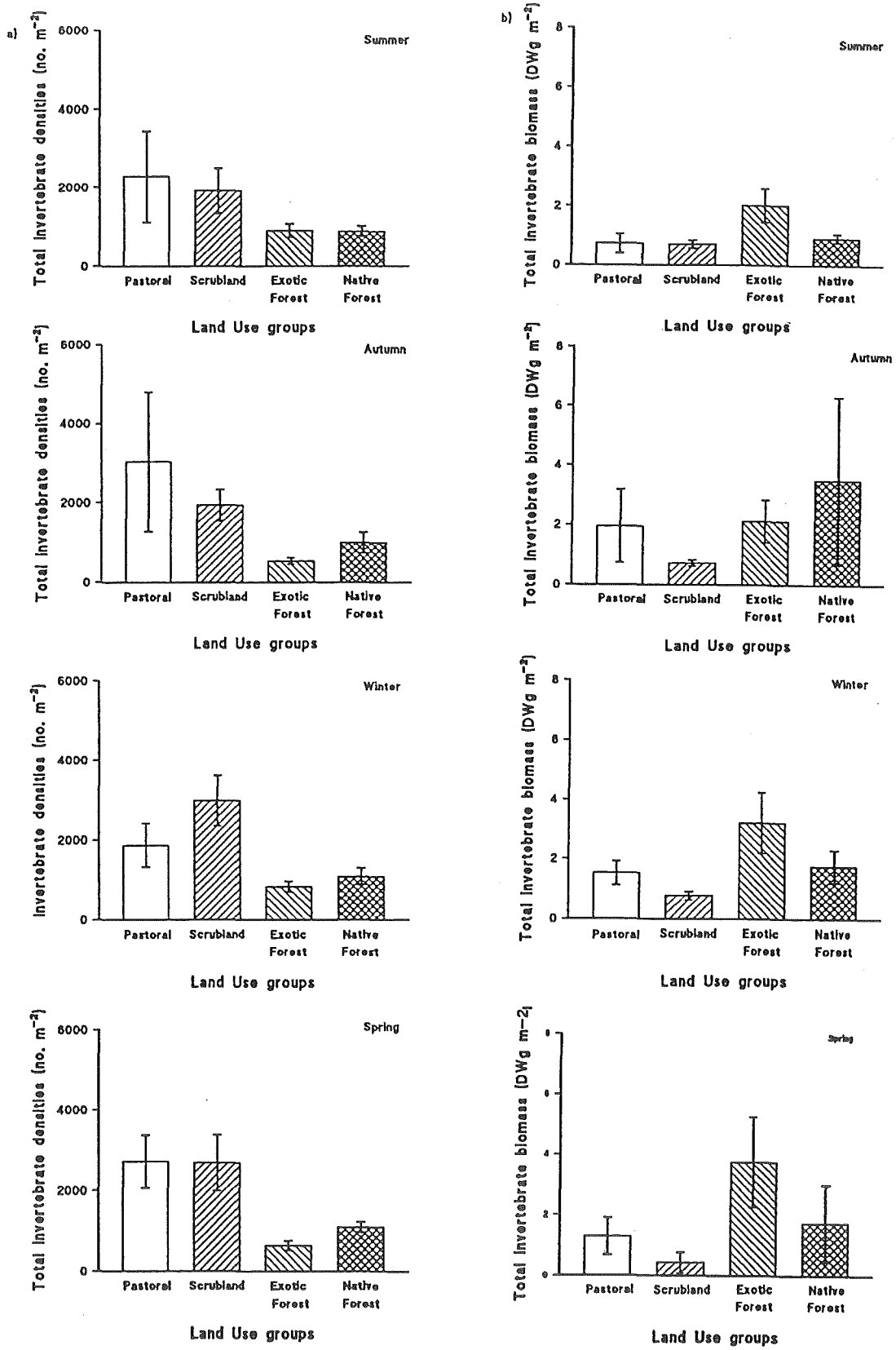


Figure 5.6 a) Invertebrate densities, and b) invertebrate biomass in streams of the four land use types in each season (±1SE; n = 4).

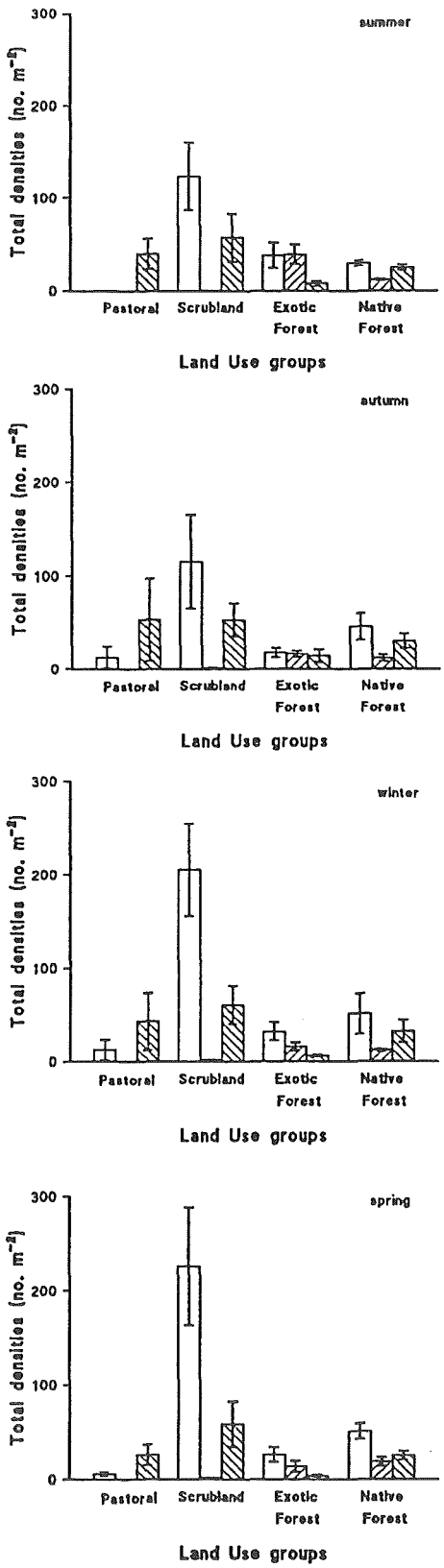


Figure 5.7 Densities of invertebrates belonging to three insect orders in streams belonging to the four land use types in each season (Open bars = Ephemeroptera, / = Plecoptera, \ = Trichoptera; ±1SE; n = 4).

Table 5.6 Comparisons between mean numbers of major taxonomic groups collected from all streams draining four land use types in four seasons (Ps = pastoral, Sc = scrub. Ex = exotic forest, Na = native forest, Su = summer, Sp = spring, Wi = winter, Au = autumn; n = 16). *F* and *P* statistics refer to two-way ANOVA results.

	Land use groups		Seasons	
	$F_{[3,64]}$	*P*	$F_{[3,64]}$	*P*
Ephemeroptera	250.06	0.01	12.71	0.01
Plecoptera	151.89	0.01	9.41	0.01
Trichoptera	89.70	0.01	0.73	n.s.
Diptera	28.75	0.01	15.30	0.01
Mollusca	67.39	0.01	2.95	0.05

Results of comparisons of means between land-use groups, and between seasons using Tukey's HSD test ($P<0.05$). High and low values indicate those groups and seasons that were significantly higher or lower.

	Land use groups		Seasons	
	Highest	Lowest	Highest	Lowest
Ephemeroptera	Sc	Ps	Sp, Wi	Su, Au
Plecoptera	Ex	Sc, Ps	Su	Wi, Sp, Au
Trichoptera	Sc	Ex, Na, Ps	-	-
Diptera	Sc, Ps	Ex	Su, Sp, Wi	Au
Mollusca	Ps	Sc, Ex, Na	Au	Wi

streams, however, *Austroperla cyrene* was more abundant than *O. feredayi*, and although not always found in native forested streams *Spaniocerca zelandica* was always collected in exotic forest streams. Scrubland streams were dominated by *Deleatidium* spp. which accounted for 56% of the fauna, and the filter-feeding hydropsychid *Aoteapsyche colonica* was always present. In contrast, hydropsychids were infrequently collected in pastoral streams and were poorly represented in forested streams (Table 5.7, Fig. 5.9). Pastoral streams were dominated by the gastropod *Potamopyrgus antipodarum*, the chironomid *Eukiefferiella* sp. and *Deleatidium* spp. (Fig. 5.9).

Two way indicator species analysis (TWINSPAN) separated the four pastoral streams from those in the three other land use categories on the first division in all seasons. The key species resulting in this separation were the trichopteran *Oxyethira albiceps*, present in pastoral streams, and five taxa (two caddis, two stoneflies and a mayfly; Fig. 5.10)

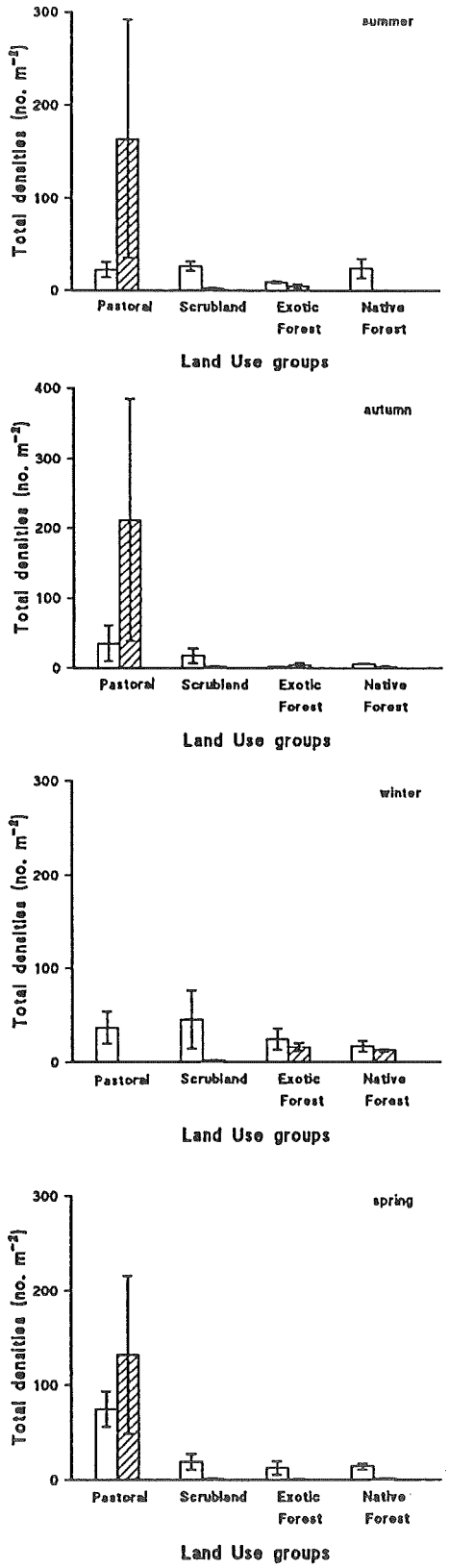


Figure 5.8 Densities of Diptera and Mollusca in streams in the four land use type in each season (Open bars = Diptera, / = Mollusca; ±1SE; n = 4).

Table 5.7 Commonly collected taxa from streams in the four land use types in all seasons

	Pastoral	Scrubland	Exotic forest	Native forest
Present in all streams in all seasons (n=16)		*Deleatidium* spp. *Aoteapsyche colonica*	*Deleatidium* spp. *Austroperla cyrene* *Spaniocerca* sp.	*Deleatidium* spp. *C. humeralis* *Stenoperla prasina* Elmidae *Olinga feredayi*
Present in 12-15 collections taken from 4 streams in 4 seasons.	*Deleatidium* spp. *Potamopyrgus antipodarum* Simuliidae *Psilochorema nemorale* *Oxyethira albiceps* *Pycnocentria* sp.	*Potamopyrgus antipodarum* *Coloburiscus humeralis* *Archichauliodes diversus* Elmidae *Eukiefferiella* sp. Simuliidae *Helicopsyche* sp. *Pycnocentria* sp.	*Stenoperla prasina* *Olinga feredayi* *Helicopsyche* sp.	*Nesameletus* sp. *P. antipodarum*

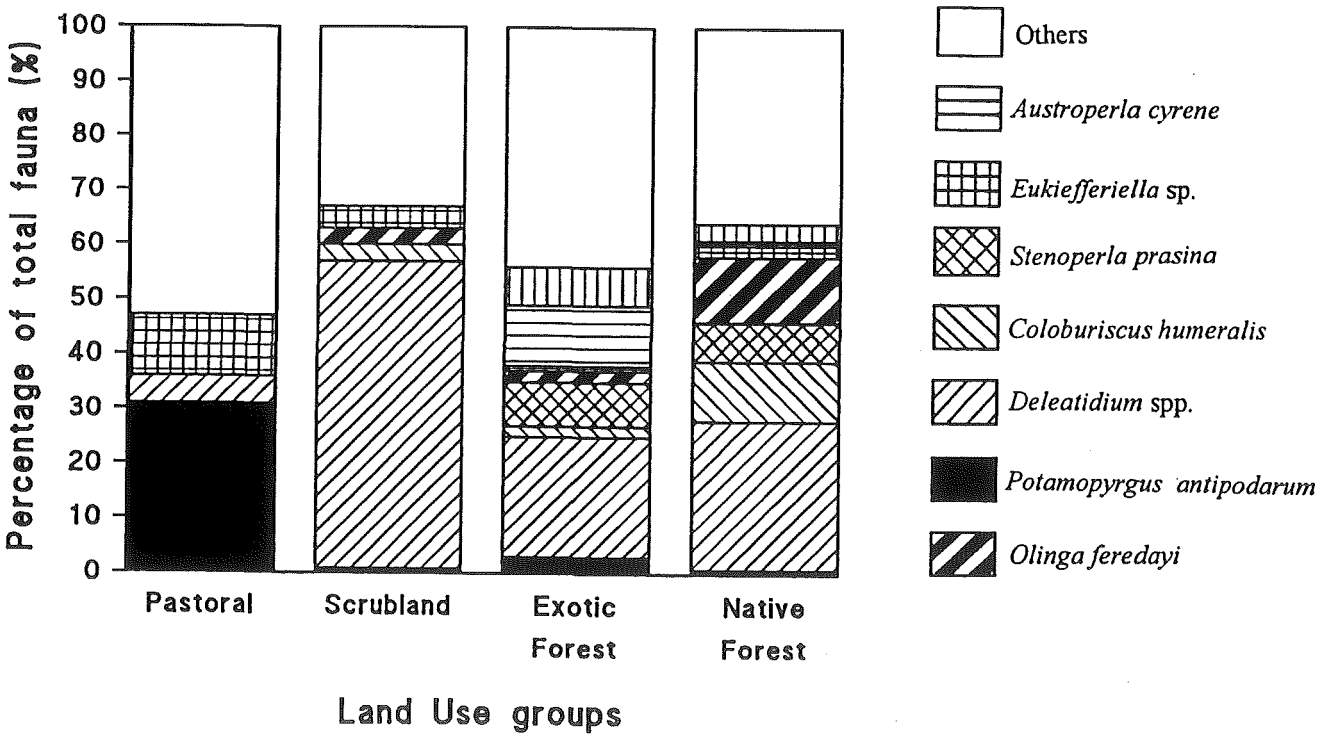


Figure 5.9 Relative abundances of common taxa in each land use group. Data are for four streams per group and four seasons of sampling. Common "Others" were molluscs, and chironomids in pastoral streams, elmids, chironomids and cased caddis in scrubland streams, stoneflies and predatory caddis in exotic and native forest streams.

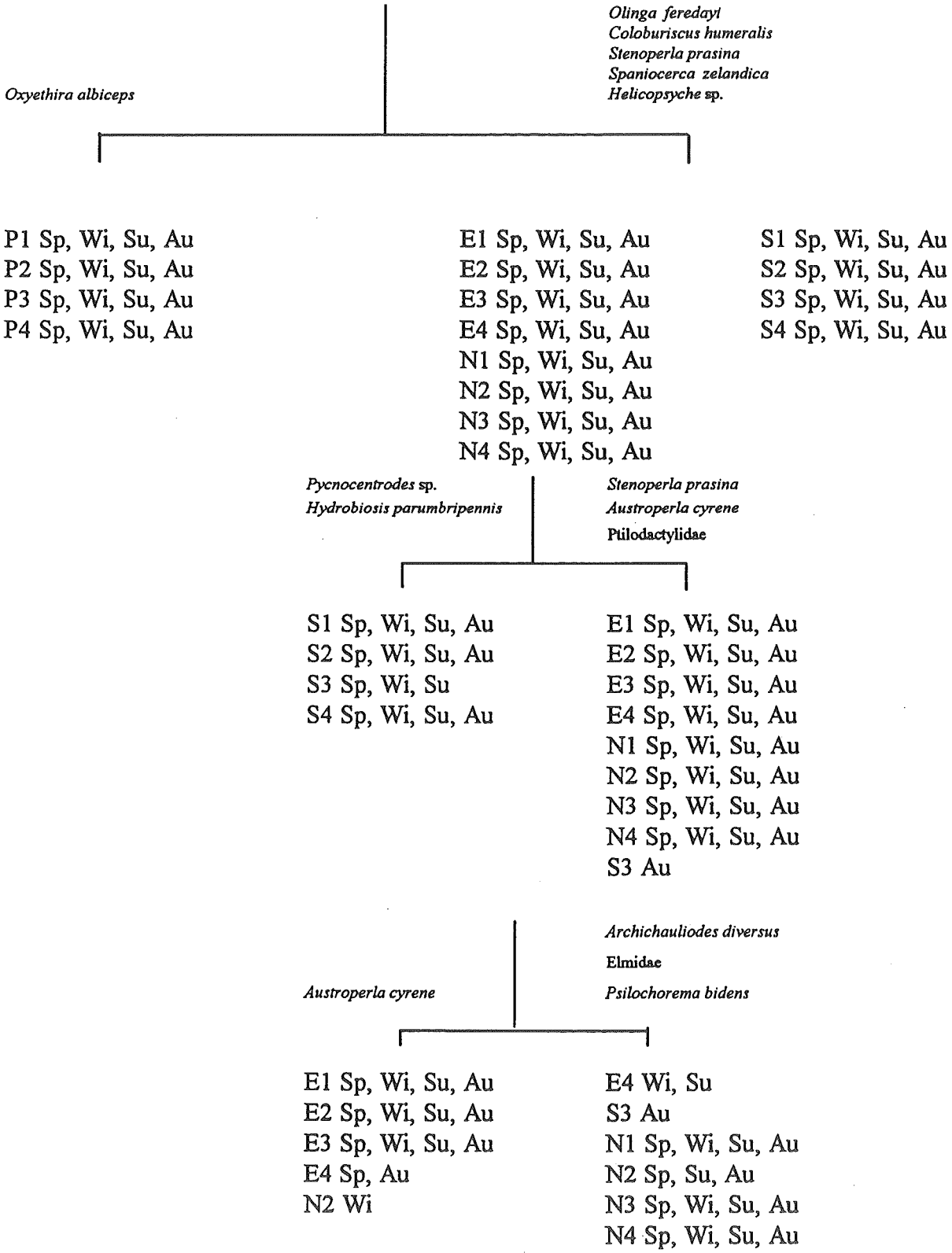


Figure 5.10 Classification of the 16 streams in four seasons using TWINSPAN and presence/absence data (P = pastoral, S = scrubland, E = exotic, N = native, Sp = spring, Wi = winter, Su = summer, Au = autumn). Indicator species are shown for each bifucation.

that were common to the other land use types. The second division separated the scrub covered streams (except for one stream in one season) from all the forested streams. The trichopterans *Pycnocentrodes* sp. and *Hydrobiosis parumbripennis* were the indicator species categorizing scrubland streams. The final TWINSPAN division separated the majority of the exotic forested streams from the native forest streams.

Detrended correspondence analysis (DECORANA) using presence/absence data resulted in three distinct groupings of streams. Pastoral streams had high Axis 1 values, whereas native and exotic forest streams had low Axis 1 values. Scrubland streams occurred between these two clusters (Fig. 5.11). Axes 1, 2 and 3 accounted for 58%, 25% and 17%, respectively, of the variance explained by the three axes.

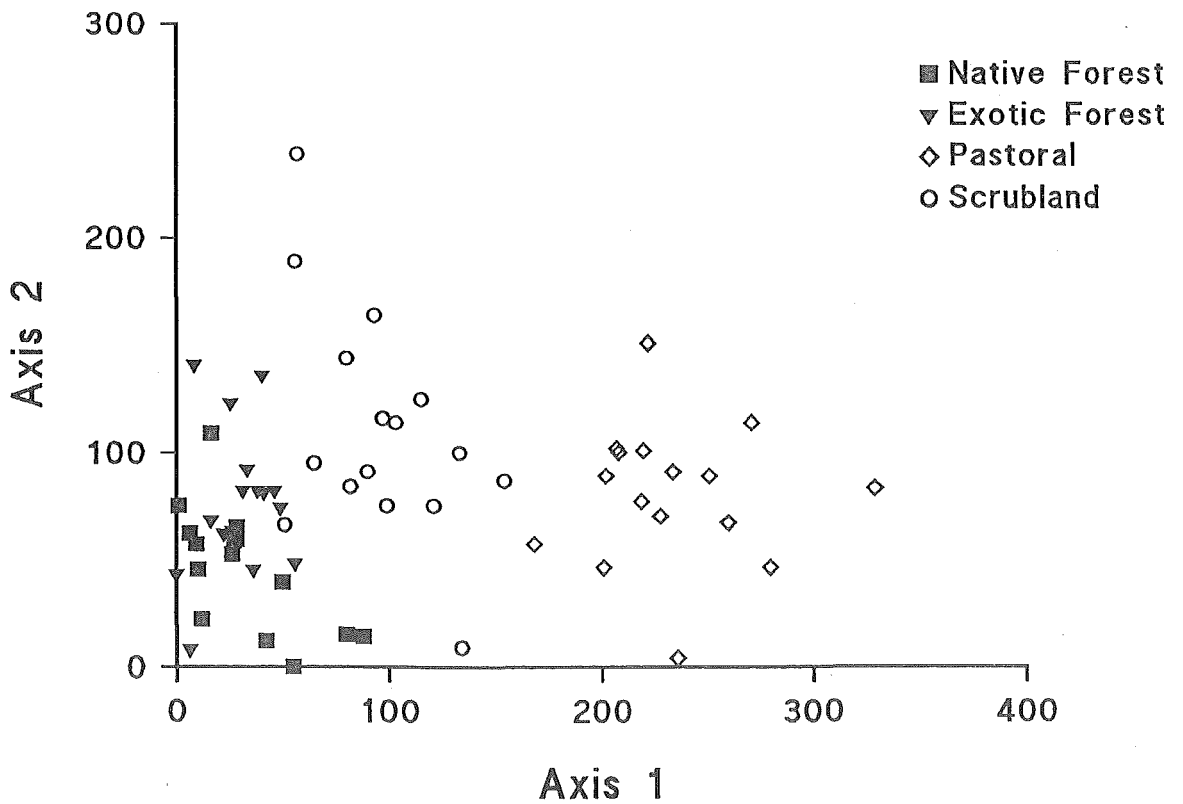


Figure 5.11 Ordination of the 16 streams in each of four seasons based on presence/absence data.

Discussion

The physical characteristics of the streams sampled in this study varied somewhat between land use groups with streams flowing through native forested catchments being larger, swifter, and with slightly larger substrates than those in exotic forests. The streams in native forest were at higher elevations than the other streams reflecting the relative ease with which lower, less-steep land can be developed for forestry and agriculture. The differences in elevation, stream size and substrate size are unlikely to be of great biological significance however, as most of the common invertebrates found in the streams occur over a wider range of current velocities, and on a wider range of substrates than recorded in this study (Jowett & Richardson 1990, Quinn & Hickey 1990, Collier 1994). Quinn et al. (in press) observed that streams in pastoral and native forest catchments of similar size and slope differed in stream width and velocity, and suggested that farmland grasses may act to stabilise streambanks as they encroach into open streambeds. At Hanmer Springs, streams belonging to these two land use groups were of similar width, and farmland grasses were present along their margins, however extensive trampling and erosion of streambanks by livestock was noted in the pastoral streams.

Stream water temperatures were lower in forested than pastoral and scrubland streams, consistent with reports on stream temperatures elsewhere (e.g. Hill & Harvey 1990, Boston & Hill 1991, Quinn et al. in press). However, the high epilithic biomass commonly associated with high temperatures of streams flowing through pastoral farmland was not observed in this study. The reason for this is unclear, however, it may be that dense grasses in the stream channel heavily shade substrates thereby limiting periphyton growth. Alternatively, disturbance by livestock may frequently reduce water clarity, increase sediment deposition, and perhaps decrease substrate stability. The standing stocks of wood, leaves, and other coarse organic materials were significantly higher in exotic and native forested streams than in open streams, and may explain the greater abundance in them of the facultative shredders *Austroperla cyrene* and *Olinga feredayi*. The obligate, leaf-shredding trichopteran *Zelandopsyche ingens* was also recorded in small numbers in the native forested

streams, but was not found in exotic forest or open streams. It has been suggested that this taxon is a beech forest specialist (Winterbourn & Davis 1976, Cowley 1978) and its absence from exotic forest streams provides support for this suggestion.

The native and exotic forest streams were also rich in ephemeropteran and plecopteran taxa, most of which were not collected in open scrub and pastoral streams. This is consistent with the findings of Quinn & Hickey (1990) and Scott et al. (1994) who noted that enrichment-sensitive mayflies and stoneflies were either absent or less abundant in streams within agriculturally developed catchments. The low number of ephemeropteran taxa collected in scrubland streams was not indicative of mayfly densities, which were significantly higher there than in forest and pastoral land streams. Scrubland stream populations were dominated by the leptophlebiid *Deleatidium*, which was also the dominant taxon in the tussock and scrubland High Country streams in my ecoregion study, and can account for well over 50% of the fauna in large South Island rivers (Pierce 1986, Sagar 1986, Scrimgeour et al. 1988, Scrimgeour & Winterbourn 1989). Although *Deleatidium* was also the most abundant taxon in native forested streams, the filter-feeding *Coloburiscus humeralis* was also common in them. *C. humeralis* feeds primarily on FPOM in suspension, and is often collected in forested streams, below swamps, and in lake outlets where plentiful food and stable substrata occur (Wisely 1962, Rounick & Winterbourn 1982, Harding & Winterbourn 1993).

Plecopteran densities were highest in exotic forest streams where *Austroperla cyrene* and *Stenoperla prasina* were abundant. *Stenoperla prasina* was also common in the native forest streams and was amongst the most abundant taxa in a wide-ranging survey of 43 New Zealand forest streams (Rounick & Winterbourn 1982). The absence of plecopterans from open streams near Hanmer is consistent with their widespread absence from streams in the three pastoral, South Island ecoregions (see Chapter 3). In contrast, several trichopterans, notably *Olinga feredayi*, *Pycnocentrodes* spp., *Pycnocentria* sp., *Helicopsyche* sp. and *Aoteapsyche* sp. were common in open streams at Hanmer Springs. These taxa were also

common in open High country streams in my summer ecoregion survey (Chapter 3) and all utilize algae as an important source of food (Cowley 1978, Winterbourn & Harding 1993, author's unpublished data). Conversely, trichopterans were poorly represented in pastoral streams, although *Oxyethira albiceps* was the TWINSPAN indicator for these sites and is commonly found in enriched streams in developed catchments (Quinn & Hickey 1990, Scott et al. 1994), especially where filamentous algae are present. Like *Deleatidium*, dipteran densities were greatest in pastoral and scrubland streams where chironomids, particularly *Eukiefferiella*, were abundant. However, the most prolific animal in pastoral streams was the snail *Potamopyrgus antipodarum*. *P. antipodarum* is commonly found in open, stable, mildly enriched streams throughout the South Island, and was associated with developed catchments with high nutrient and periphyton levels in the 88 rivers surveyed by Quinn & Hickey (1990).

Analysis of seasonal water chemistry data indicated that chemical conditions (except alkalinity) did not differ significantly between seasons. However, both the number of invertebrate taxa collected, and overall invertebrate densities were significantly lower in autumn than in the other seasons. This was true for all the main insect orders, but Mollusca were more abundant in autumn. The reduction in taxonomic richness and densities of insect taxa in autumn was unexpected, as many New Zealand aquatic insects have their major emergence periods in spring and summer (for example at Cass at a similar altitude in the central South Island, K.Shearer pers comm.), and their progeny would be expected to be abundant in streams by autumn. Low autumn densities of larvae could not be explained by storm events or extended high flows during this period, and indeed much higher rainfall was recorded in September, November and December when larval densities were higher (Fig. 5.4). The general lack of pronounced seasonal changes in invertebrate densities is consistent however, with the view that many New Zealand stream invertebrates have poorly synchronised life cycles (Towns 1981, Winterbourn et al. 1981).

The lower taxonomic richness and a paucity of enrichment-sensitive taxa in pastoral

streams at Hanmer indicates that factors associated with substantial catchment development strongly influence benthic faunas. These findings are consistent with those of other studies undertaken elsewhere in New Zealand (e.g. Allen 1959, Quinn & Hickey 1990, Taranaki Regional Council 1991, Scott et al. 1994). Quinn & Hickey (1990) noted a 21% decrease in taxonomic richness in streams draining highly modified catchments compared with streams in catchments with little agricultural development, and marked declines in ephemeropteran, plecopteran, trichopteran and megalopteran biomass. Similarly, Scott et al. (1994) noted that *Deleatidium*, *Pycnocentrodes* sp., *Olinga feredayi*, *Archichauliodes diversus*, *Aoteapsyche colonica* and general plecopteran densities decreased as the degree of pasture development increased in a study of three Southland streams.

Streams within the four land use types considered in this study represented a series of progressively more modified systems. The most "pristine" were *Nothofagus* forested streams, followed by those in exotic plantations, then streams in cleared and scrub covered catchments, and finally streams in highly modified and intensively developed agricultural catchments. DECORANA indicated that invertebrate assemblages in streams associated with each of these land use activities showed a sequential change in structure and faunal composition along this "ecological gradient", from taxonomically diverse, mayfly and stonefly dominated communities in pristine streams, to low taxonomic diversity communities with few if any mayflies and stonflies and a predominance of molluscs, oligochaetes and chironomids in highly modified pastoral streams (see Fig. 5.12). TWINSPAN also separated stream communities in the four land use categories in order of degree of catchment modification with pastoral streams being separated first, followed by scrubland streams, and then the two forest communities.

It is clear that differences in vegetation and land use both between and within ecoregions result in substantial (but predictable) differences between invertebrate assemblages of streams. My ecoregion classification does not take account of land use activities which differ from those identified as "characteristic" of an ecoregion, but to be a useful

management tool it will need to do so. As I have shown, catchments subject to greater human modification than is considered "characteristic" of that particular ecoregion can be expected to have reduced taxonomic diversity, and depending on the degree of human modification a reduction in the number of enrichment-sensitive taxa and a corresponding increase in tolerant invertebrate species. A series of ecoregional subdivisions which attempt to account for these land use effects are proposed in Chapter 6.

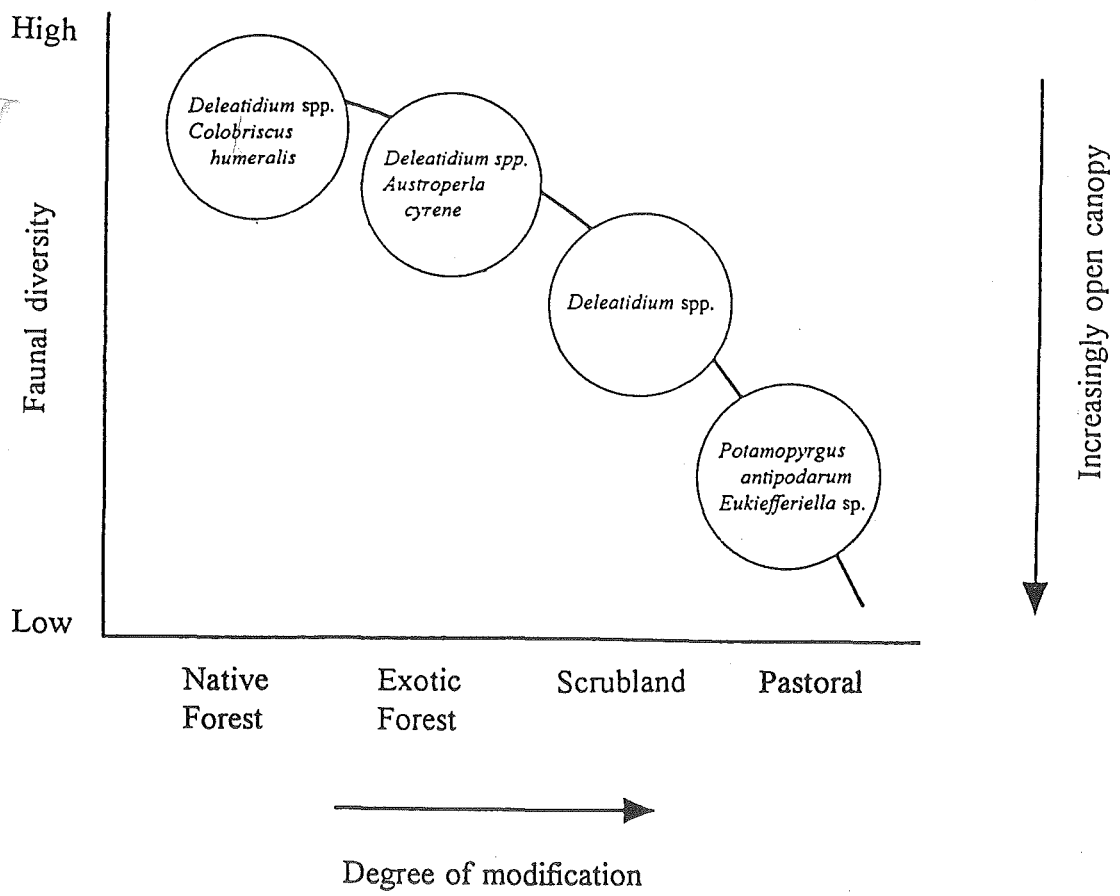


Figure 5.12 A summary of changes in stream invertebrate communities as the degree of catchment modification increases. Numerically dominant taxa of each "land use community" are shown.

Chapter 6

Synopsis

Lotic Ecoregions

The primary aim of my study was to develop an ecoregion classification for lotic systems in New Zealand based on macro-environmental factors. Having achieved this I wanted to assess whether the proposed ecoregions represented areas of different water chemistry and had different benthic invertebrate faunas.

Analysis of the benthic communities of the 100 streams generally supported the distinctiveness of my lotic ecoregions. Of the ten ecoregions, only the three pastoral ones had streams with benthic assemblages that could not be linked unambiguously with them. Typically, a reduction in community distinctiveness occurred from ecoregions with streams in "pristine" catchments to those in highly modified ecoregions. The specificity of the fauna decreased along this pristine-modified gradient with high taxonomic richness, and high numbers of endemic species in the little modified catchments of North-west Nelson, Westland, and the South-east Forest, and low taxonomic richness, few endemic taxa and more "enrichment tolerant" benthic communities in those ecoregions with high human land use; i.e. Central Otago, Southland Plains and East Coast Plains. The observed reductions in diversity are considered to result primarily from the interaction of three primary macro-environmental conditions; historical biogeographical events, climatic conditions, and differing vegetation and land use activities. The ecoregions that were least affected by human modification were also those often cited as possible refugia from Pleistocene glaciations (i.e. North-west Nelson and Westland), and therefore the high diversity in these ecoregions may result from these two factors working together. It is conceivable that the most anthropogenically affected ecoregions may also have been areas of high endemism prior to

deforestation and land development by humans. Circumstantial evidence suggesting this is provided by the high endemism of taxa recorded in underground waters of the East Coast Plains (Collier 1993).

My comparison of streams in catchments supporting different land use activities provided further insight into the contention that changes in land use, particularly agricultural development, can play a major role in reducing taxonomic diversity of stream faunas. Streams in catchments ranging from relatively "pristine" native forest to extensive pastoral development in the same ecoregion showed a progressive reduction in taxonomic diversity and community complexity. In an attempt to test the relative importance of ecoregional differences and land use effects, I ordinated the community data from the summer sampling season for native forest (mixed *Nothofagus* spp.) and the pastoral streams from the Hanmer Springs (High Country ecoregion) land use study, with the ecoregion community data for neighbouring North-east Nelson (also predominantly *Nothofagus* forest) and the pastoral East Coast Plains. Although there were only four streams in each land use type from near Hanmer Springs, they were sampled and analysed using the same protocol, and examined at the same time of year as those in the ecoregion study. Interestingly, all four groups of streams clustered out separately (Fig. 6.1). However, groups of streams with similar vegetation/land use from the two ecoregions, clustered most closely together. These results indicate that regional factors are not totally overridden by land use changes.

Results of the water chemistry analyses were less conclusive. Several ecoregions were found to have distinctive water chemistry profiles influenced by high or low concentrations of particular chemical variables, which tended to be associated with differences in catchment geology. However, catchment geology could not satisfactorily explain the composition of water chemistry profiles in all streams. In several ecoregions the importance of other factors could be detected readily, e.g. sea spray fallout in South-east Forest and Banks Peninsula streams resulted in high sodium and chloride concentrations, whereas very high rainfall and rapid surface runoff in the Southern Alps is partially responsible for the low ion

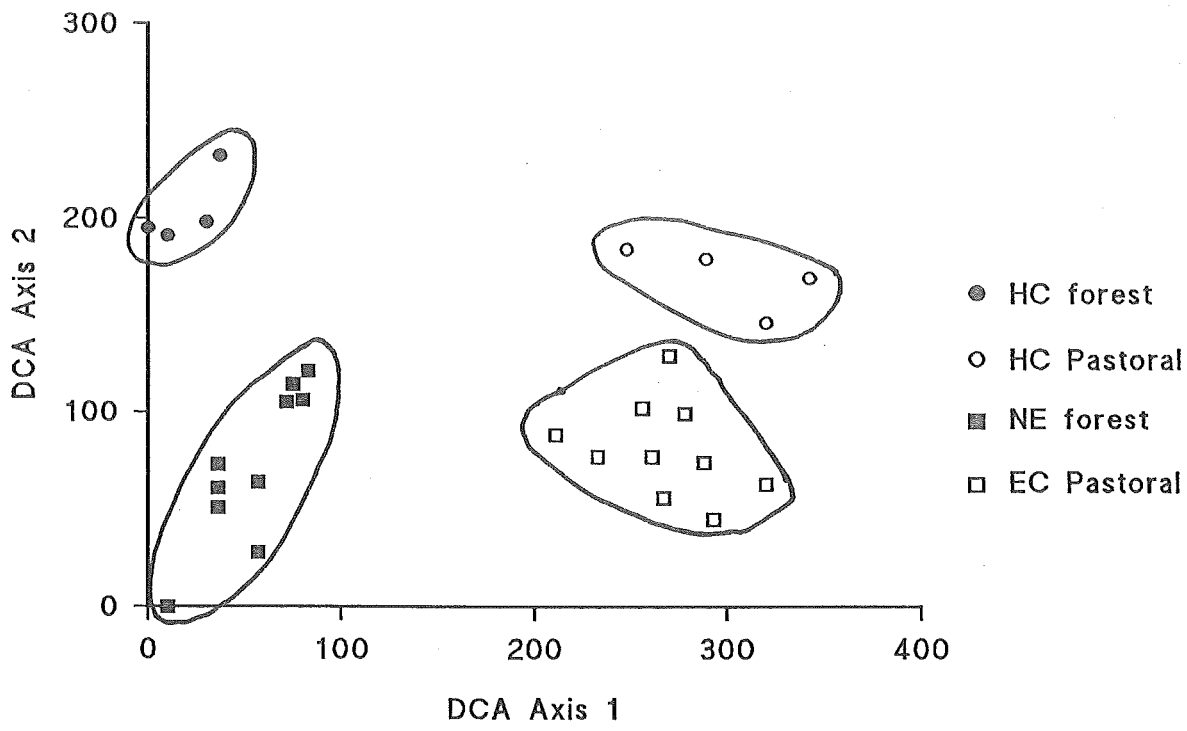


Figure 6.1 DECORANA ordination of streams in three ecoregions, East Coast Plains (EC), North-east Nelson Forest (NE) and High Country (HC) to compare the relative importance of regional and land use differences (see text for details).

concentrations of alpine streams (Winterbourn & Ryan 1994). Nevertheless, high variability in major ion concentrations was observed in several ecoregions, and probably reflects catchment-level or smaller-scale differences in vegetation, climate and the residence time of groundwater, a condition affected by landform, valley slope, aspect, and soil profile (Drever 1982, Bache 1983). All these factors can be expected to influence the rate at which ions are mobilised into groundwaters (Bache 1983). The usefulness of specific chemical variables (e.g. conductivity in the South-east Forest, and alkalinity in North-east Nelson) rather than the entire chemical profile for defining ecoregions corroborates the findings of Close & Davies-Colley (1990a,b) who concluded that specific anions and cations best characterised regional groupings of rivers.

In order to compare differences between ecoregions using both water chemistry and macroinvertebrate communities as criteria I plotted Axis 1 ordination values for

macroinvertebrate communities (see Chapter 3) against water chemistry Axis 2, which was correlated with more chemical variables than Axis 1 (see Chapter 4). The resultant graph (Fig. 6.2) showed a wide spread of the 100 streams with reasonably tight groupings of streams within some ecoregions, which nevertheless overlapped considerably. The result of this analysis implies that ecoregions are better defined on the basis of water chemistry and invertebrate assemblages, than by using either criterion alone. In the "100 rivers" study conducted in New Zealand by Biggs et al. (1990), borderline catchments were assigned to ecoregions on the basis of bedrock type, flow variability, and water quality (assessed mainly using conductivity data) factors they considered were of major importance in determining biological community structure. As my ecoregion classification was developed using bedrock type, and incorporated information on flow conditions (I used rainfall and regional climatic data), I plotted streams as ordinated along Axis 1 using benthic invertebrate data (Chapter 3

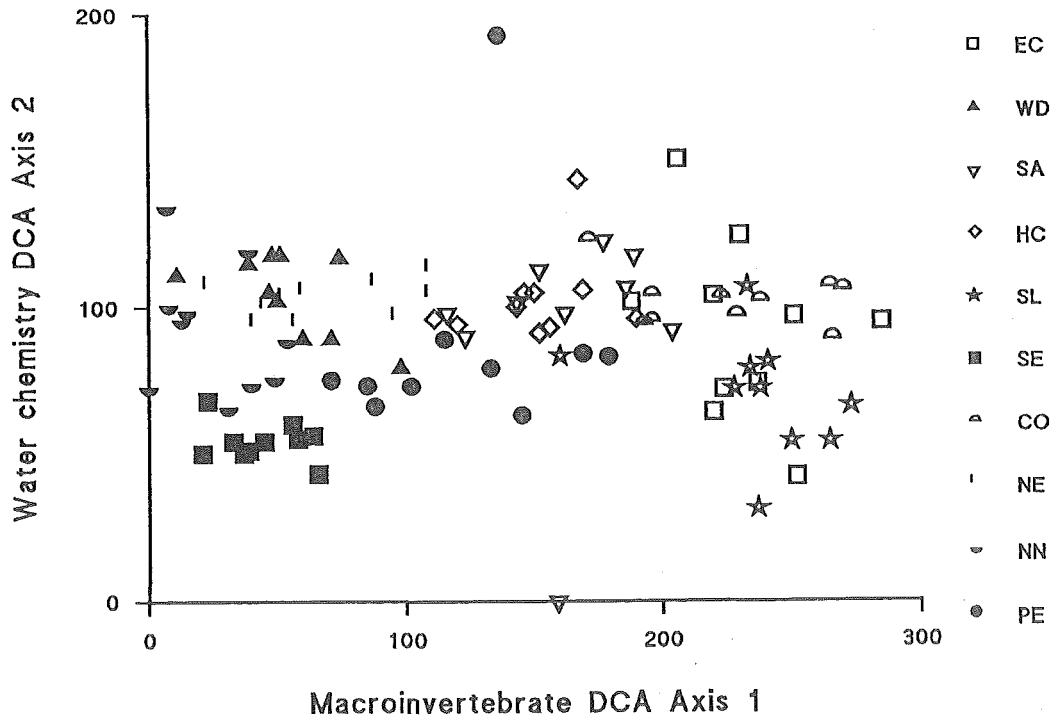


Figure 6.2 Plot of ordination values of all 100 streams on macroinvertebrate DCA Axis 1 and water chemistry DCA Axis 2. See Figures 3.8 and 4.7 for parent ordinations.

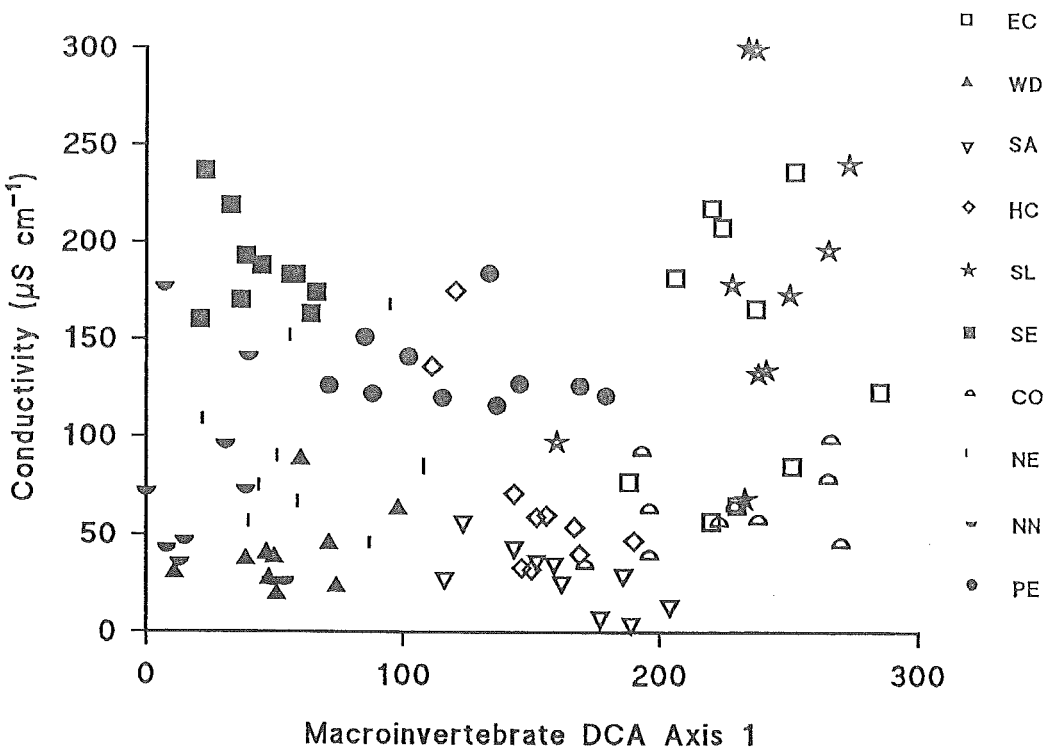


Figure 6.3 Ordination of streams on macroinvertebrate DCA Axis 1 plotted against conductivity values for each of the 100 streams.

and Fig. 6.2) against conductivity values for each stream (Fig. 6.3). Several ecoregions, specifically the South-east Forest, the Southern Alps, Banks Peninsula and Westland formed tight clusters. Conductivity separated streams on ecoregional grounds better than Axis 2 of the water chemistry DCA (Fig. 6.2), although it is apparent that the relationship between conductivity, invertebrate assemblages and ecoregions is not a simple one.

Another question that I have not previously addressed is what influence macro-environmental variables have on streams and rivers of differing sizes. My study focussed on small headwater streams which were considered most likely to be influenced by climatic and geomorphological conditions and did not address the question of stream size, directly. However, a comparison of the fauna collected in small streams in the East Coast Plains ecoregion in my study, with the fauna recorded in large braided rivers in the same ecoregion (Pierce 1976, Sagar 1986, Scrimgeour et al. 1988, Scrimgeour & Winterbourn 1987) shows

the presence of very dissimilar invertebrate assemblages. Large braided river communities were dominated by the leptophlebiid *Deleatidium*, and the trichopterans *Aoteapsyche* spp. and *Hydrobiosis* spp.; in contrast, small headwater streams had faunas dominated by the gastropod *Potamopyrgus antipodarum*, chironomids and the trichopterans *Pycnocentria evecta* and *Pycnocentrodes* spp. Undoubtedly, the faunas of larger rivers in other ecoregions also show weak correspondence with the faunas of small streams. It would be surprising if this was not the case since faunistic changes are the norm along river systems (e.g. Vannote et al. 1980, Statzner & Higler 1985), although changes may be less pronounced where river systems are short and provide physically harsh environments as on the West Coast of the South Island (Harding 1992). The general similarity of the faunas of the few South Island rivers considered by Biggs et al. (1990) is therefore not unexpected, as they were considerably larger (median flow of 10.2 $m^3 s^{-1}$) than my headwater streams (mean flow about 0.003 $m^3 s^{-1}$).

Ecoregional subdivisions

The discussion so far has focused on the applicability of the ecoregion classification, however my land use study (Chapter 5) provided insights into the limitations of the classification as well. Thus, it is apparent that the invertebrate faunas of small streams can diverge to varying extents from the fauna that "typifies" a region depending on local variations in land use/vegetation, climate and relief. Similarly, thermal spring outflows, swamp seepages, intermittent streams and lake outlets will have faunal assemblages differing from "the norm" for the ecoregion. A tentative hierarchical subdivision of stream types within ecoregions is proposed in Figure 6.4 based on the findings of Chapters 3 and 5. Cover (vegetation/land use) is considered to be the most important measurable variable (biogeographical effects are probably unmeasurable) within an ecoregion likely to influence community composition, and the fundamental separation is into open or closed canopy streams. Closed-canopy streams may support distinctive faunas depending on the type of riparian vegetation, e.g. beech forest

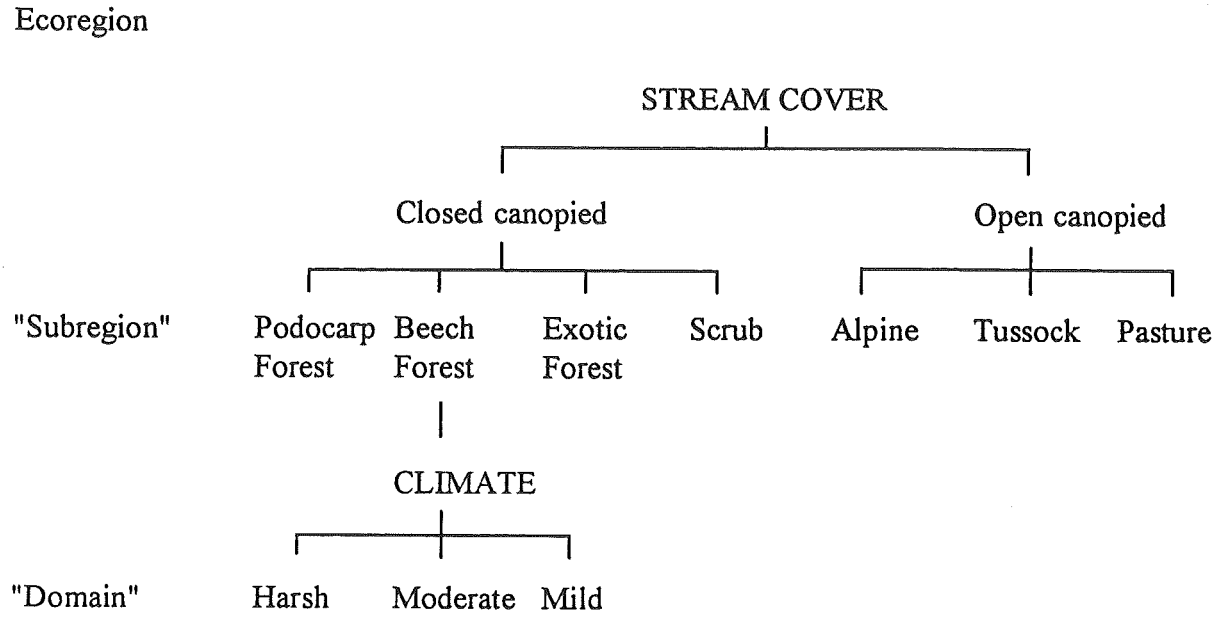


Figure 6.4 Proposed hierarchical subdivisions for the lotic ecoregion classification. The factors delineating subregions are in capitals.

streams compared with those in exotic forest, or scrub. Subregions based on vegetational criteria may be further defined or subdivided on the basis of the severity of climatic conditions. I have arbitrarily suggested three climatic categories, harsh, moderate, and mild, which could differ in terms of rainfall, temperature ranges and associated stability (see e.g. Death & Winterbourn 1994). I have made no attempt to test these subdivisions empirically, and it will probably require intensive and long-term monitoring of catchments over a wide geographical area to do so.

Impact of macro-environmental forces

A fundamental tenet of my lotic classification is that water chemistry, hydrology and benthic communities of stream ecosystems are controlled by a combination of interacting macro-environmental variables; geology, climate, and land use (see Chapter 1). These primary "driving" variables, are predicted to have a critical influence on the physico-

chemical templet of a stream by determining catchment slope, topography, hydrology, and water chemistry, factors which in turn have major effects on the abundance and diversity of the benthic fauna. My findings indicate that the importance of each macro-environmental condition will vary from ecoregion to ecoregion (Fig. 6.5). For example, the influence of human activities in modifying catchments (e.g. through agriculture) on streams is generally greater in the East Coast Plains ecoregion than in North-west Nelson. In highly ''modified'' ecoregions such as the East Coast Plains, land use activities may be the single most important macro-environmental variables modifying stream chemistry and biota, and their effects may be so great as to almost nullify the influence of other primary variables. Not withstanding this, it is clear that past biogeographical events also have a very important influence on invertebrate community composition, and provide a ''species template'' which helps define the limits of benthic communities.

In summary, the results of my research support the premise that relatively homogenous geomorphological regions exist within the South Island, regions that can be defined by their climate, geology and vegetation, and which possess distinct stream communities whose composition is influenced by these macro-environmental factors. The magnitude, and effect of individual environmental factors is still not properly understood, and further research on their specific effects is needed to increase our understanding of distributional patterns and benthic invertebrate assemblage structure in New Zealand streams.

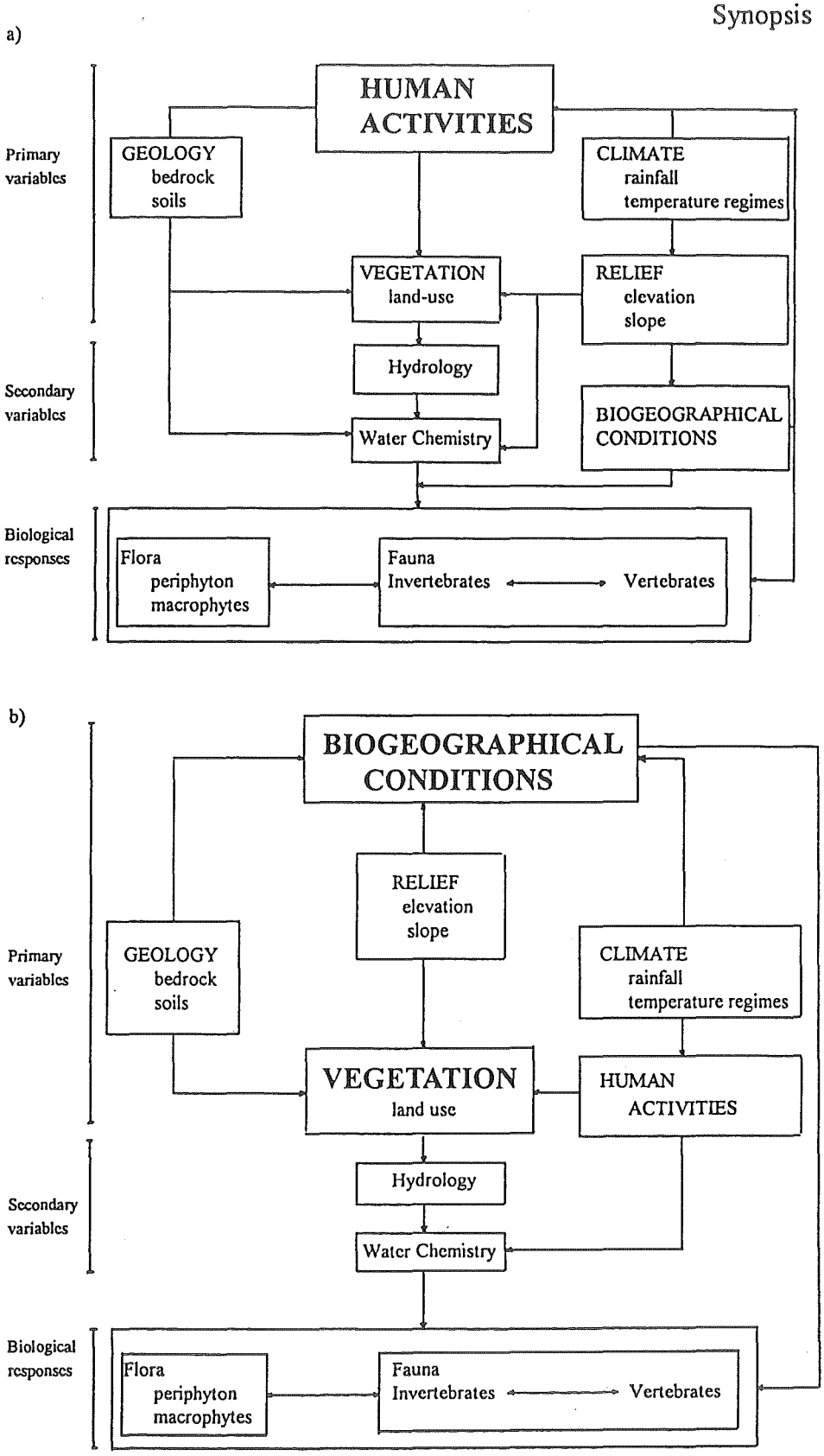


Figure 6.5 A hierarchical model showing the major variables influencing water chemistry, and the flora and fauna of stream ecosystems, and major linkages between them (Modified from Biggs et al. 1990). The importance of variables is indicated by font size, a) the model in an anthropogenically modified ecoregion, such as the East Coast Plains, and b) in a "pristine" ecoregion with little human modification, such as North-west Nelson.

Acknowledgements

This study was only possible because of the support and encouragement I received from many people. In particular, I am indebted to Mike Winterbourn, for his willingness to share his knowledge, time, and literary skills with me. My apologies to him for my inability to read, write and spell accurately (I blame the school teachers). Thanks also to Colin McLay for acting as a co-supervisor, and John Quinn who provided the original idea for this study.

The Department of Conservation provided financial support for this project (Contract 1495).

Numerous others encouraged, advised and assisted, in particular members of the "stream team": Lindsay Chadderton, Russell Death, Kevin Collier, Alistair Suren, Mark Sanders and Jennifer Tank. I also thank Neil Deans, Kevin Collier, Tracey Robinson, Mandy Tocher, Richard Holdaway, Raphael Didham, Mark Brabyn, Lyn de Groot, Jan MacKenzie, Barry van Beurten and Gerard Davey for help and encouragement. Thanks to Tas Carryer and John Scott who assisted with my computing difficulties (except the colour map!). Russell and Mark advised me on statistical matters, although any statistical errors in this work are solely my own. Special thanks to Richard and Tracey for their comments on parts of this thesis.

Access to the GIS was possible because of the generosity of FRI/Landcare, and I particularly thank Martin Fastier, Tom Pearson, and Mac McLellan for their invaluable help. Thanks also to Wayne McDiffett, at Bucknell University, who put in considerable effort analysing cations and anions from 130 stream water samples.

Finally, I am very grateful to my family who encouraged and supported me throughout this study, and I would like to extend my gratitude to the staff and students of the Zoology Department, who provided a friendly and supportive work environment.

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Appendices

Notes

1. The GIS software TERRASOFT (Digital Resources 1991) is a PC IBM compatable package requiring a minimum of 8M RAM, colour VGA, and 386 microprocessor. Large map files are created often requiring 20+M, so a large hard drive capacity is required.

2. Voucher specimens of all taxa collected in the 100 stream ecoregion survey have been deposited at the Canterbury Museum.

Appendix 1. New Zealand Meteorological Service Climatic Regions (1983).

Region code	Climate description
A_1	Warm humid summers, mild winters. Annual rainfall 1000 to 1500 mm with a winter maximum.Prevailing wind southwest but occasional strong gales and heavy rains east and north of Hamilton.
A_2	Similar to A_1 but wetter. Annual rainfall 1500 to 2500 mm.
B_1	Very warm summers and mild winters. High sunshine hours, though high intensity rains received in the north and northeast. Annual rainfall 1000 to 2000 mm with a winter maximum.
B_2	Less sunny than B_1. Cooler winters with frequent ground frosts.
C_1	Very warm summers, day temperatures occasionally above 30°C with dry foehn northwesterlies. Annual rainfall 1000 to 1500 mm; greatly reduced in spring and summer. Moderate winter temperatures with maximum rainfall in winter.
C_2	Drier than C_1, rainfall 600 to 1000 mm. Summer droughts common.
C_3	Cooler and wetter than C_1. Very heavy rain at times from south and southeast. Annual rainfall 1500 to 2500 mm.
D_1	Prevailing westerly-northwesterly winds. Annual rainfall 900 to 1300 mm, evenly distributed across the seasons. Warm summers and mild winters.
D_2	Wetter than D_1 with annual rainfall 1300 - 2000 mm.
E_1	Prevailing winds southwesterlies, with minimum rainfall in winter in the south. Small temperature range.
E_2	More sheltered than E_1, with little seasonal rainfall range but large tempera ture range. Frequent winter frosts.
F_1	Low annual rainfall 500 to 800 mm. Warm summers with occasional hot foehn northwesterlies. Cool winters with frequent frosts, and occasional snow.
F_2	Cooler and wetter than F_1 with rainfalls 800 to 1500 mm. Northwesterlies common. Snow may lie on the ground for weeks in winter.
F_3	Semi-arid areas with annual rainfall 300 to 500 mm. Very hot summers and cold winters.

G_1	Warm summers and cool winters. Rainfall 500 to 900 mm evenly distributed but slight winter minimum.
G_2	Wetter than G_1 with rainfall 900 to 1300 mm. Generally windier with frequent showers in coastal districts.
M	High rainfall mountain climates. Conditions vary greatly with altitude and exposure.

Appendix 2. Physical characteristics of the 100 streams sampled between December 1992 and March 1994 (tr = tributary, dr = drain, wt = water race). Physical stream measurements are mean values from 3-5 recordings; see Chapter 3 for details.

Code	Stream	Location (Lat. Long.)	Elev. (m)	Temp. (°C)	Width (m)	Depth (cm)	Current (m s^{-1})	Substrate Index
WD1	L.Kaniere tr	171 09' 42 48'	140	8.8	0.75	6.7	0.13	4.7
WD2	Noone Ck	170 15' 43 16'	105	8.8	1.50	6.3	0.20	5.0
WD3	Fox Sm	170 01' 43 28'	166	8.6	2.00	8.0	0.13	4.9
WD4	Near Donegals	171 17' 42 44'	200	8.4	0.75	4.0	0.18	4.8
WD5	Kaniere R. tr	171 06' 42 46'	120	6.8	0.86	6.0	0.19	5.0
WD6	Near Makawhio	169 44' 43 33'	20	12.0	0.60	6.3	0.23	5.2
WD7	Ruera tr	169 40' 43 34'	30	11.1	0.50	6.0	0.24	4.8
WD8	Fox 8	169 24' 43 44'	20	11.1	0.90	9.6	0.29	5.1
WD9	Fox 9	169 23' 43 45'	25	11.0	0.50	7.3	0.18	5.3
WD10	Windbag Ck tr	169 22' 43 46'	20	10.0	0.40	7.0	0.30	5.1
EC1	Wildon dr	172 23' 43 40'	15	12.4	1.50	30.6	0.14	4.6
EC2	Upper Cam R	172 35' 43 20'	20	9.7	1.00	28.3	0.14	4.9
EC3	Upper Ohoka R	172 34' 43 21'	25	16.1	0.75	13.0	0.30	4.8
EC4	Lakeside dr	172 18' 43 47'	12	11.8	1.00	25.3	0.40	4.6
EC5	Aylesbury wt	172 16' 43 32'	100	14.3	0.70	16.0	0.40	4.9
EC6	Amberley Sm	172 43' 43 09'	50	12.7	0.90	18.6	0.23	4.2
EC7	Styx R	172 35' 43 29'	20	11.0	2.30	16.3	0.29	4.7
EC8	Barr Hill wt	171 51' 43 40'	280	14.0	1.00	10.0	0.31	5.5
EC9	B & Vaughan wt	171 46' 43 35'	270	12.5	1.70	15.0	0.29	4.6
EC10	Ashburton wt	171 54' 43 49'	110	13.0	0.70	9.6	0.28	4.7
CO1	Lauder Sm	169 40' 45 03'	320	15.0	1.20	25.3	0.29	4.1
CO2	Becks Ck	169 44' 44 59'	360	15.0	0.90	15.0	0.29	4.3
CO3	Gorge Ck	169 57' 44 58'	600	15.0	0.60	12.0	0.15	4.8
CO4	Spain Ck	169 48' 45 04'	520	15.0	0.60	9.3	0.19	4.1
CO5	Wetherburn	170 00' 45 03'	560	16.0	1.20	16.0	0.29	4.6
CO6	Eweburn	170 05' 45 07'	400	17.0	1.40	13.6	0.30	5.0
CO7	Idaburn	170 00' 45 00'	600	18.0	2.30	21.6	0.30	4.9
CO8	Hills Ck	169 55' 44 57'	580	17.0	1.30	8.3	0.21	5.5
CO9	Young Hill Ck	169 29' 45 09'	220	14.0	0.90	11.0	0.31	4.0
CO10	Waikerike Sm	169 22' 45 11'	200	16.0	1.10	6.3	0.23	4.9
PE1	Kinloch tr	172 47' 43 48'	180	10.7	0.60	16.3	0.18	5.7
PE2	Te kawa tr	172 46' 43 41'	300	10.7	1.20	9.6	0.19	5.2
PE3	Holmes Ck	172 52' 43 40'	60	11.1	0.70	11.0	0.20	5.2
PE4	Upp Pawsons	172 56' 43 43'	390	10.2	1.00	10.0	0.24	4.8
PE5	Okuti tr	172 48' 43 47'	45	11.1	1.20	11.3	0.16	5.5
PE6	Tautamata	172 59' 43 46'	60	11.3	1.50	15.6	0.29	5.7
PE7	Grehan Ck	172 59' 43 48'	130	10.1	0.80	12.3	0.24	4.9
PE8	Balgueri Sm	172 58' 43 48'	80	11.4	0.60	12.6	0.28	6.2
PE9	Wainui Ck	172 52' 43 48'	160	10.0	1.20	8.0	0.20	5.2
PE10	Waiheke Ck	172 54' 43 46'	90	12.6	0.55	6.3	0.28	5.2
HC1	Longslip Ck	169 39' 44 35'	750	12.7	2.0	14.0	0.30	6.0
HC2	Clent Hill Ck	171 10' 43 32'	600	14.0	2.1	16.0	0.33	5.1
HC3	Gabriels Gully	172 43' 42 34'	370	12.1	1.4	18.0	0.29	5.0
HC4	Camp Sm	172 44' 42 34'	360	10.0	1.2	15.0	0.23	4.6

Code	Stream	Location (Lat. Long.)	Elev. (m)	Temp. (°C)	Width (m)	Depth (cm)	Current (m s^{-1})	Substrate Index
HC5	Coach Sm	171 43' 43 17'	933	14.6	1.0	7.3	0.27	5.3
HC6	Dry Sm	171 42' 43 15'	900	14.0	1.2	10.3	0.28	4.6
HC7	Bullocky Ck	170 34' 44 05'	700	14.1	0.6	6.0	0.16	5.2
HC8	Mossy Sm	170 33' 43 55'	740	10.7	0.9	8.0	0.24	5.1
HC9	Ohau tr	170 33' 43 54'	800	8.5	0.7	9.6		5.3
HC10	Paddy's Market Sm	170 39' 44 04'	620	13.1	2.0	9.6	0.29	5.5
SE1	Ryans Ck	168 05' 46 53'	60	9.2	0.8	6.3	0.17	4.6
SE2	Fern Gully Ck	168 04' 46 53'	70	9.3	0.7	5.6	0.14	4.7
SE3	Horseshoe Bay Ck	168 07' 46 52'	20	9.5	0.5	3.0	0.18	3.9
SE4	South Maori R. tr	168 04' 46 51'	20	9.0	0.4	6.3	0.14	4.9
SE5	Port William Ck	168 04' 46 50'	60	9.7	0.5	6.0	0.18	4.3
SE6	Bush Cone tr	169 12' 46 34'	160	9.1	0.8	5.3	0.14	5.7
SE7	Longbeach tr	169 15' 46 34'	180	9.7	0.6	6.0	0.16	6.9
SE8	Chaslands tr	169 23' 46 35'	160	9.0	0.6	7.0	0.21	5.5
SE9	Cathedral tr	169 29' 46 30'	200	9.0	0.5	5.0	0.25	5.4
SE10	Florence Sm	169 32' 46 29'	210	10.5	0.4	5.6	0.21	4.2
SL1	Ryal Bush Ck	168 20' 46 17'	50	14.3	1.4	13.0	0.18	4.6
SL2	Swales Ck	168 17' 46 05'	70	14.0	1.2	15.6	0.14	4.5
SL3	Near Roe Burn	168 21' 45 43'	220	14.3	0.9	6.6	0.20	5.1
SL4	Roy Sm	168 12' 45 43'	300	14.7	1.1	8.6	0.24	5.2
SL5	Bonds Ck	168 10' 45 46'	260	12.0	0.8	9.0	0.23	5.3
SL6	Larnach Sm	168 47' 45 57'	60	19.9	0.9	7.3	0.28	5.3
SL7	McGregor Sm	168 42' 45 58'	80	20.5	1.2	10.0	0.32	5.0
SL8	Roslyn Bush Sm	168 27' 46 21'	40	12.5	2.0	12.0	0.14	3.7
SL9	Waikiwi Sm	169 29' 46 19'	45	13.2	1.5	18.3	0.35	4.0
SL10	Tussock Ck	168 20' 46 17'	70	13.9	1.8	21.6	0.23	4.4
SA1	Upper Otira tr	171 32' 42 53'	1100	4.0	0.6	5.6	0.29	5.6
SA2	L.Mavis inflow	171 38' 42 54'	1620	4.4	1.5	6.3	0.18	5.3
SA3	Stocking Sm tr	170 05' 43 42'	920	9.4	1.5	5.6	0.24	5.4
SA4	Stocking tr 2	170 05' 43 41'	900	8.1	0.8	14.0	0.23	6.2
SA5	Treble Cone Ck	169 53' 44 37'	1500	5.0	0.6	8.0	0.13	5.1
SA6	Marion tr 1	168 03' 44 46'	860	17.0	0.4	4.3	0.24	5.9
SA7	Marion tr 2	168 03' 44 45'	850	12.0	0.6	9.0	0.20	5.6
SA8	Homer tunnel tr	167 56' 43 46'	1050	5.4	0.7	5.6	0.23	5.2
SA9	Wakefield Sm	170 08' 43 41'	1040	4.1	0.8	6.0	0.20	5.6
SA10	Blue tr	170 09' 43 41'	960	4.0	0.5	8.3	0.21	6.2
NN1	Fossil Ck tr	172 26' 40 49'	210	12.9	0.7	7.0	0.19	5.6
NN2	Brown R. tr	172 21' 40 50'	210	14.1	0.6	6.7	0.18	5.2
NN3	Buller tr 1	172 12' 41 46'	250	10.1	0.5	6.0	0.22	4.8
NN4	Flat ford Ck	172 07' 41 47'	240	10.3	0.8	7.3	0.23	5.1
NN5	Near Lyell Sm	172 05' 41 48'	240	10.5	0.5	4.0	0.27	4.9
NN6	Ten mile Ck tr	171 16' 42 20'	40	11.0	0.5	3.0	0.14	5.1
NN7	Taylorville Ck	171 17' 42 26'	60	11.7	0.6	9.3	0.23	5.0
NN8	Drummonds Ck	172 44' 41 05'	680	10.2	0.5	5.3	0.22	4.6
NN9	Mt. Peel Ck	172 36' 41 07'	840	7.5	0.6	11.0	0.21	5.2
NN10	Galatea Sm tr	172 40' 41 06'	760	11.1	1.4	12.3	0.25	5.5

Code	Stream	Location (Lat. Long.)	Elev. (m)	Temp. (°C)	Width (m)	Depth (cm)	Current (m s^{-1})	Substrate Index
NE1	Whangamoa tr 1	173 25' 41 13'	300	10.0	0.5	7.0	0.18	4.8
NE2	Whangamoa tr 2	173 27' 41 13'	320	10.3	0.5	3.7	0.20	6.0
NE3	Pelorus tr 1	173 34' 41 18'	80	12.1	1.5	3.7	0.13	5.1
NE4	Elvy tr	173 33' 41 18'	60	12.1	1.2	15.0	0.25	5.2
NE5	The Brook tr	173 18' 41 19'	320	11.2	0.9	11.7	0.29	5.9
NE6	Maitai Valley Sm	173 21' 41 17'	140	11.0	0.6	10.0	0.21	5.2
NE7	Ronga Saddle Ck	173 36' 41 08'	300	10.7	1.8	9.3	0.21	5.6
NE8	Okiwi Valley tr	173 38' 41 06'	180	12.1	0.6	9.0	0.18	5.2
NE9	Six mile Ck	172 57' 41 46'	570	10.1	1.8	14.3	0.29	5.3
NE10	Near Rotoiti tr	172 54' 41 46'	740	12.0	1.2	9.0	0.29	5.3

Appendix 3. Macroinvertebrate faunas of the 100 streams in 10 ecoregions (Numbers m^{-2}).

Westland Rainforest Ecoregion (WD)

	WD1	WD2	WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10
PLATYHELMINTHES										
Neppia montana	4	4	16			4	14			9
ANNELIDA										
Lumbriculus variegatus	23	20		220		76	34		12	
Pristina sp.						30	20	50		
Telmatodrilus multiprostatus			20						10	
Stylodrilus sp.	40	7			201					
Limnodrilus hoffmeisteri					218					
MOLLUSCA										
Potamopyrgus antipodarum	7		1282				126	2		
Sphaerium novaezelandiae			2							
Planorbarius corneus						2				
CRUSTACEA										
Ostracoda			2		9		2			
Paracalliope sp.					2	2				
INSECTA										
EPHEMEROPTERA										
Coloburiscus humeralis	302	230	274			103	4	99		
Nesameletus sp.		5	4			4	414			20
Ameletopsis perscitus	2			2	2	2			2	5
Neozephlebia scita	36					4	9	9		11
Zephlebia dentata	29		176		4					
Deleatidium spp.	104	355	131	223	452	349	499	175	32	104
Austroclima jollyae						5	23	4		
PLECOPTERA										
Stenoperla prasina	13	2	4	20	23	4	16	20	5	7
Austroperla cyrene	50	9	85	14	20	5	65	5		50
Acroperla trivacuata								16		
Acroperla spiniger				2						
Zelandoperla decorata						34		11	32	158
Zelandoperla denticulata										9
Zelandobius sp. A.		7	11							
Zelandobius confusus						23	13	94		
Zelandobius furcillatus	29	2	2	52	97	9			14	7
Zelandobius unicolor								2	79	45
Spaniocerca zelandica	5	7		126						5
Spaniocerca minor									2	
Cristaperla fimbria					2					4
Halticoperla viridans						4				
Spaniocercoides sp.		27			74					5
Spaniocercoides philpotti				248			4	5	5	
MEGALOPTERA										
Archichauliodes diversus		2				4				

	WD1	WD2	WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10
COLEOPTERA										
Elmidae			20			2		4		
Scirtidae sp A.				4						
Scirtidae sp B.				11						
Ptilodactylidae	2		4							
Hydrophilidae				4					2	
Rhantus pulverosus									4	2
DIPTERA										
Limonia nigrescens										
Eriopterini sp.	2		7		20	2				
Nothodixa sp.							2			
Eukiefferiella sp.	17						14			
Paucispinigera approximata	17									37
Naocladius sp.		112	7							
Chironomus sp.				347						
Polypedilum sp.				348	338		10		10	37
Orthoclad sp.					339					
Macropelopiini sp.						58		40	10	
Tanytarsus sp.							10		14	
Diamesini sp A.		111	7					20	10	
Maoridiamesa sp.								25		
Cricotopus sp.									13	
Simuliidae ungulatum	10	4	61			20	43	63	22	2
Tanyderidae										
Empididae sp. A		5	2	7	2	16				
Empididae sp. B (hairy)	4	2	5	4	9					2
Empididae sp. C (elong)								2		2
Empididae sp. D							22			
Paralimnophila skusei	2	2	2				4			2
Hexatomini										
?*Molophilius* sp.							13			
Aphrophila neozelandica		20								
Ceratopogonidae					2					
Stratiomyidae						2				
Psychodidae						2				
Neocurupira campbelli							2			
TRICHOPTERA										
Diplectrona zelandensis	4	36								
Diplectrona sp.A	16									
Polyplectropus puerilis					2					
Plectrocnemia maclachlani				2						
Hydrobiosella stenocerca	9					52	16	14	11	9
Hydrobiosella mixta										
Hydrochorema crassicaudatum				4						
Hydrochorema tenuicaudatum		5							5	
Hydrobiosis sp.	9	9	23		49	5		4		9
Hydrobiosis silvicola	9	5		5		4	27	2	13	
Hydrobiosis parumbripennis										
Hydrobiosis frater		2								

	WD1	WD2	WD3	WD4	WD5	WD6	WD7	WD8	WD9	WD10
Hydrobiosis spatulata			11							
Hydrobiosis charadraea			4							
Hydrobiosis clavigera						2				
Psilochorema sp.						2				
Psilochorema nemorale	9	9	11	18	13		7	9		9
Psilochorema bidens								4	5	
Psilochorema sp. A					36					
Costachorema callista							2			
Costachorema psaroptera										
Costachorema sp. A			4							
?Traillochorema spp.									4	
Olinga feredayi		4	7				11	7	4	
Confluens sp.					2					
Helicopsyche spp.	36							9		
Rakiura vernale	38	49	41	16	7		9	4	52	2
Pycnocentria evecta			2			2		92	9	7
Pycnocentria sylvestris		9		4						
Hudsonema amabilis	2	2		2				2	4	4
Hudsonema aliena			2							
Pycnocentrella eruenus	18									
Oeconesus sp.			4				2			
Philorheithrus agilis			9							
Beraeoptera roria										
Zelolessica cheira		13			122	2	2			
Zelolessica meizon				2						
Zelandopsyche ingens										
Total density	848	1076	2242	1685	2045	835	1439	793	385	563
Total taxa	30	31	33	24	25	32	31	29	27	27

East Coast Plains Ecoregion (EC)

	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	EC9	EC10
PLATYHELMINTHES										
Neppia montana	85	13	2			5		31		2
ANNELIDA										
Pristina sp.	1401									
Limnodrilus hoffmeisteri	503							1001		250
Stylodrilus sp.		214	470	14	277		28	1170	500	
Nais sp.						227				
Lumbriculus variegatus						160			2002	1053
Telmatodrilus multiprostatus										610
Nematode							6			
MOLLUSCA										
Potamopyrgus antipodarum	893	1663	1035	56	112	877	4	418	90	130
Gyraulus spp.		4	7		1					
Sphaerium novaezelandiae	121	268	515		2	5			5	11
Physa acuta	245	63	299		112	14			38	40
CRUSTACEA										
Daphnia?							227			
Ostracoda	498	86	13	13	7	2	286			2
Paracalliope sp.	716	1433	162	2279						
Chiltonia sp.								146		
INSECTA										
Culex sp.							106			
Sigara sp.		4				2				
EPHEMEROPTERA										
Deleatidium spp.	700	43	153	4	454	4		79	88	77
COLEOPTERA										
Elmidae	2			2	108			16	653	603
DIPTERA										
Chironomus sp.	2						220			
Eukiefferiella sp.	3	9	4			120		236		
Tanytarsus vespertinus		21	4		1					
Macropelopiini sp.		11		18	1				490	
Corynoneura sp.			4							
Orthoclad sp			4			142				180
Cricotopus sp.				19			140			
Polypedilum sp.				12						
Maoridiamesa sp.						80	200		302	328
Naocladius sp.							122			
Simuliidae			4			38	171	2	13	4
Tanyderidae	2							4	2	7
Empididae sp. A										
Muscidae	5						4		2	
Paralimnophila skusei	4	7				2				
Hexatomini										
Aphrophila neozelandica									104	58

	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	EC9	EC10
Ephydridae							9			
Psychodidae							4			
Stratiomyidae									2	
TRICHOPTERA										
Aoteapsyche colonica	194			635	1424					299
Aoteapsyche raruraru										
Polyplectropus puerilis	2	2		9						
Hydrobiosis sp.	2	4			5			2		22
Hydrobiosis silvicola										
Hydrobiosis parumbripennis			2	13	49	7		7	47	9
Hydrobiosis umbripennis									9	
Psilochorema nemorale	76	41	4	18	11	2		2	14	16
Olinga feredayi								2		
Pycnocentria evecta	207	144	5	409	20			274		34
Pycnocentrodes spp.	223	167	16	56	79	31		306	77	387
Hudsonema amabilis	412	198	2	74	4	4		9	536	209
Oxyethira albiceps	2	126	7	27	13		119			7
Oeconesus sp.	9	4	2							11
Total density	6307	4525	2714	3658	2680	1722	1646	3705	4974	4351
Total taxa	24	22	21	17	18	18	15	17	19	25

Central Otago Basin (CO)

	CO1	CO2	CO3	CO4	CO5	CO6	CO7	CO8	CO9	CO10
PLATYHELMINTHES										
Neppia montana	27	5		2	4					
ANNELIDA										
Telmatodrilus multiprostatus	539				572	10				
Stylodrilus sp.	320	214	1049	4404	120		36	90	241	
Limnodrilus hoffmeisteri		130								
Lumbriculus variegatus				2080		8				
Nais sp.							65	59		506
MOLLUSCA										
Potamopyrgus antipodarum	2273	382	2142	1109	49		2	2	855	
Gyraulus spp.		5	241	2						2
Sphaerium novaezelandiae	333	13	110	31					20	
Physa acuta	9	34	180	32				2		
Lymnaea spp.		2	41	5						
Physastra variabilis										4
CRUSTACEA										
Paracalliope sp	2455	13					4	2	54	
Ostracoda	121	5	22	4						
INSECTA										
Xanthocnemis zealandica	4	4		13						
Sigara sp.				5	2	2				
EPHEMEROPTERA										
Deleatidium spp.	2	67	23	2	605	45	178	652	117	2
PLECOPTERA										
Stenoperla prasina							7			
Zelandoperla decorata						2				
MEGALOPTERA										
Archichauliodes diversus					2		2	11		
COLEOPTERA										
Elmidae	378	182	31	4	486	2	122	211	164	7
DIPTERA										
Eriopterini sp.						4	9	2	2	
Cricotopus sp.	6	249	10			500	136	12		9
Eukiefferiella sp.	5		62	1	80	263	120	8		
Polypedilum sp.		199								
Macropelopiini				1					11	
Orthoclad sp					42					
Maoridiamesa sp.						250		14		
Naocladius sp.									9	9
Simuliidae ungulatum	121	36	2	90	171	227	126	104	25	
Muscidae	4	7	4							
Paralimnophila skusei	4									
Aphrophila neozelandica	2									
Tabanidae	2									

	CO1	CO2	CO3	CO4	CO5	CO6	CO7	CO8	CO9	CO10
TRICHOPTERA										
Aoteapsyche colonica	2	13	14	2	47	18				
Polyplectropus puerilis	11									
Plectrocnemia maclachlani	11									
Hydrobiosis sp.	2	18	2	11	2	7	47	4		
Hydrobiosis parumbripennis	2	20	4	18	5	5	18	29	4	
Hydrobiosis frater	14	9								
Psilochorema bidens	5	4	11	7	9					
Olinga feredayi	2	14	77							
Pycnocentria evecta	9	2	4	5	72	466				
Pycnocentrodes spp.	130	801	34							
Hudsonema amabilis	31	86	103	16	29	2				
Oxyethira albiceps	72	7	4	2	2					
Total density	6639	1764	4040	7785	2361	1322	898	2258	2040	540
Total taxa	18	24	17	15	21	12	18	22	14	10

North East Nelson Forest (NE)

	NE1	NE2	NE3	NE4	NE5	NE6	NE7	NE8	NE9	NE10
PLATYHELMINTHES										
Neppia montana	11	38	25	16	2	29	5	11	29	4
ANNELIDA										
Nais sp.	54		80	20		403		124	64	12
Stylodrilus sp.		20			10		21		22	
Pristina sp.				11			60			
Lumbriculus variegatus			55		15					6
Limnodrilus hoffmeisteri	25									
MOLLUSCA										
GASTROPODA										
Potamopyrgus antipodarum	13	52	27	88	2	34	2	2	20	
Gyraulus spp.									2	
CRUSTACEA										
Chiltonia sp.		20								
Paraleptamphopus caeruleus			2							
Ostracoda			2							
INSECTA										
EPHEMEROPTERA										
Coloburiscus humeralis	45	27	95	916	14	198	97	126	52	5
Nesameletus sp.	2	7	16	4			7	72	4	
Ameletopsis perscitus									7	
Neozephlebia scita	13	45	11	32		22	5	94	7	
Zephlebia dentata	29	7	13	4			9	14		
Deleatidium spp.	124	194	184	526	110	236	167	274	607	1102
Austroclima sepia						2				
Austroclima jollyae									18	
Oniscigaster distans									11	
PLECOPTERA										
Stenoperla prasina	4	7	5	9	2	9	9	4	7	11
Austroperla cyrene	5	13	13	14	2	16	2	4	11	2
Acroperla trivacuata			4					2		
Acroperla spiniger					2				2	
Zelandoperla decorata	2	2	4	5			4	23	4	23
Zelandobius confusus	196		88	38	40	5	113		50	581
Zelandobius furcillatus		31						79		4
Zelandobius unicolor								5		
Spaniocerca zelandica		13						11		
Spaniocerca zwicki	43			7						
Spaniocerca bicornuta			5		14	4	5			
Cristaperla fimbria	4	4	4	2				2		5
Spaniocercoides sp.										
Megaleptoperla diminuta								2		
MEGALOPTERA										
Archichauliodes diversus				4		13			47	
COLEOPTERA										
Elmidae	2	7	2	2	2	103	20	4	94	2

	NE1	NE2	NE3	NE4	NE5	NE6	NE7	NE8	NE9	NE10
Scirtidae	2									
Ptilodactylidae		2	2		2		4			
Hydrophilidae					2					
DIPTERA										
Limonia nigrescens	2			2						
Eriopterini sp.										4
Nothodixa sp.			4							
Eukiefferiella sp.	76	14	61	10						
Polypedilum sp.	77	16	58	65	20	61		49	10	
Paucispinigera approximata		15					9			
Macropelopiini sp.		16								8
Orthoclad sp					20					
Diamesini sp. A.							10			
Maoridiamesa sp.						62			11	
Naocladius sp.						62				8
Cricotopus sp.									10	
Chironomus sp.							10			
Simuliidae	2	7		9	2	16	4		4	11
Tanyderidae										
Empididae sp. A			2					2	2	2
Empididae sp. B (hairy)							2			
Empididae sp. C (elong)									2	
Psychodidae	2									
Aphrophila neozelandica				9	2	43			140	4
Neocurupira campbelli							4			
TRICHOPTERA										
Diplectrona zelandensis	230	263	110				88	124	11	
Aoteapsyche colonica				38	4	889	7	5		11
Aoteapsyche raruraru						7				
Polyplectropus puerilis	5					4		4		
Hydrobiosella stenocerca	20	18	4	72		2	7	41		2
Hydrobiosella mixta										
Hydrochorema crassicaudatum			2							
Hydrobiosis sp.	7	4	11		5	11	7		9	29
Hydrobiosis silvicola	2							4		
Hydrobiosis parumbripennis						5			7	2
Hydrobiosis frater										
Hydrobiosis charadraea									4	
Psilochorema sp.								2		
Psilochorema nemorale	13	2	14	5				16		4
Psilochorema bidens	4					4	5		14	2
Costachorema callista					4					11
Neurochorema forsteri						4				
Olinga feredayi	11	5	7	40	2	68	2	20	90	2
Conuxia gunni										2
Helicopsyche spp.	13	4	185	85	9	52	4	9	250	

	NE1	NE2	NE3	NE4	NE5	NE6	NE7	NE8	NE9	NE10
Pycnocentria evecta	18	36	25				22	4	2	5
Pycnocentria sylvestris	2	4	4	4						
Oxyethira albiceps						32				
Philorheithrus agilis									13	4
Beraeoptera roria				2					225	
Zelolessica meizon								2		
Total density	1058	879	1063	2029	301	2396	711	1135	1872	1868
Total taxa	33	29	32	28	24	29	30	31	37	29

North West Nelson Ecoregion (NN)

	NN1	NN2	NN3	NN4	NN5	NN6	NN7	NN8	NN9	NN10
PLATYHELMINTHES										
Neppia montana	7		7		7				13	
ANNELIDA										
Nais sp.	61	12	65		672	571	446		25	18
Stylodrilus sp.		6	60					227	40	
Lumbriculus variegatus			30		120					
Slavina sp.				259						
MOLLUSCA										
GASTROPODA										
Potamopyrgus antipodarum			7						7	
CRUSTACEA										
Paraleptamphopus caeruleus			146	8	9	4			2	
Paracalliope sp.				6						
INSECTA										
EPHEMEROPTERA										
Coloburiscus humeralis			23		9		4			
Nesameletus sp.	5	9	2	23	2			5	56	14
Ameletopsis perscitus	5	4					2			
Neozephlebia scita	18	36			5		58	5		
Zephlebia dentata	5	23	25	34	14	18	34	23		5
Deleatidium spp.	149	22	302	157	263	155	128	36	364	151
Atalophlebioides cromwelli		2								
PLECOPTERA										
Stenoperla prasina	9		4	2	5	2		7	7	2
Austroperla cyrene		2	14	5	5			5	2	5
Acroperla trivacuata			2		2					
Acroperla spiniger									5	
Zelandoperla decorata	5		11			2		2	2	11
Zelandobius confusus	81		16		18	25		95		
Zelandobius furcillatus	7		18	22	41	49	67		77	22
Zelandobius unicolor										2
Spaniocerca zelandica				4	16		9		16	7
Spaniocerca zwicki								4		
Cristaperla fimbria			2	4	2	18		14	11	2
Spaniocercoides sp.		2	4					22		
Spaniocercoides cowleyi	2									
Spaniocercoides howesi					13					
MEGALOPTERA										
Archichauliodes diversus		4								
COLEOPTERA										
Elmidae	2			2		4	2		9	11
Scirtidae		2					9	2		
Ptilodactylidae			23		7					

	NN1	NN2	NN3	NN4	NN5	NN6	NN7	NN8	NN9	NN10
Hydrophilidae				2		2		4		
DIPTERA										
Eriopterini sp.	2		9		2	2	4	2		
Nothodixa sp.			2						2	
Cricotopus sp.	11						23			
Paucispinigera approximata	20			60	166		42	62	52	
Macropelopiini sp.	10							26		
Eukiefferiella sp.		4				6				12
Diamesini sp. A.			109	30						
Tanytarsus sp.			30	83						
Polypedilum sp.						14	14			
Naocladius sp.										4
Simuliidae	5	2			5				16	11
Tanyderidae										
Empididae sp. A			7	2	2			2	2	2
Empididae sp. B (hairy)		4	2					5	2	
Paralimnophila skusei		9	5							
?*Molophilus* sp.								4		
Aphrophila neozelandica		2							2	
TRICHOPTERA										
Diplectrona zelandensis	13			5	2		2	5	4	
Aoteapsyche colonica								2		
Aoteapsyche rarurarau		14	54							
Polyplectropus puerilis		2						4		
Hydrobiosella stenocerca	5	23	27	76	14	13	22	67	7	9
Hydrochorema crassicaudatum								4		
Hydrochorema tenuicaudatum			2		4		2		5	
Hydrobiosis sp.	5	11		11	13	2				
Hydrobiosis sp B.			13						11	
Hydrobiosis silvicola		4		2				9		20
Hydrobiosis parumbripennis		2								
Psilochorema sp.	2			7		2				
Psilochorema nemorale					11			14	5	
Psilochorema bidens	4		16	4			13			
Costachorema callista			4	2	4				9	5
Costachorema psaroptera										
Olinga feredayi								2	5	
Helicopsyche spp.	9		92					5	22	
Rakiura vernale	2	11	4	47		4				9
Pycnocentria evecta	4		7					13		
Pycnocentria sylvestris			7	2				5		
Hudsonema amabilis	2	2								2
Oeconesus sp.										
Pseudoeconeus sp.			2							
Philorheithrus agilis										
Beraeoptera roria										
Zelolessica cheira									11	
Zelolessica meizon			13						7	
Allocentrella sp.		2								

	NN1	NN2	NN3	NN4	NN5	NN6	NN7	NN8	NN9	NN10
Traillochorema spp.								2		
?*Tarapsyche olis*										5
?*Synchorema* spp.										5
Total density	450	216	1166	859	1433	893	881	693	799	324
Total taxa	27	26	38	26	28	18	18	34	31	21

Southern Alps Ecoregion (SA)

	SA1	SA2	SA3	SA4	SA5	SA6	SA7	SA8	SA9	SA10
PLATYHELMINTHES										
Neppia montana	41			45	329					2
Cura pingius			4			13	4	2		
ANNELIDA										
Telmatodrilus multiprostatus	4			9		29	50	9	2	5
Nais sp.				2						
Stylodrilus sp.					29					2
MOLLUSCA										
GASTROPODA										
Gyraulus spp.								2		
INSECTA										
Collembola							2			
EPHEMEROPTERA										
Nesameletus sp.				41	77					
Deleatidium spp.	59		491	184	1429				29	31 2
PLECOPTERA										
Acroperla trivacuata								2		
Acroperla spiniger	27									
Nesoperla fulvescens								4		
Zelandoperla decorata	22		4		14		2	2		2
Zelandobius confusus	175					18		2		
Zelandobius furcillatus			394	185	63				4	9
Spaniocerca zelandica				2						
Spaniocercoides sp.								2		
COLEOPTERA										
Elmidae	27				90				4	
Scirtidae				2					128	9
DIPTERA										
Limonia nigrescens	2					2				
Eriopterini sp.					2		5			2
Maoridiamesa sp.	45	25		69	20				12	80
Macropelopiini sp.	20	20		50	19					
Eukiefferiella sp.			11	80	11	18		6	30	
Orthoclad sp	15		9							19
Naocladius sp.						16				
Cricotopus sp.							2	5	10	
Simuliidae	41			41					5	
Empididae sp. C (elong)						4				2
Muscidae	2								2	13
Neocurupira hudsoni									5	
TRICHOPTERA										
Aoteapsyche colonica	16								4	

	SA1	SA2	SA3	SA4	SA5	SA6	SA7	SA8	SA9	SA10
Hydrobiosis sp.			9	11	3				2	2
Hydrobiosis silvicola	4									
Hydrobiosis parumbripennis				7				2	4	4
Costachorema sp.					9				2	
Costachorema callista				4	7					
Edpercivalia maxima	2									
Pycnocentria evecta				4						2
Pycnocentrodes spp.	2									
Oxyethira albiceps				4		2				
Tiphobiosis sp A.						4				
Total density	504	45	922	740	2102	106	65	67	245	155
Total taxa	17	2	7	17	14	9	6	12	15	15

South Eastern Forests (SE)

	SE1	SE2	SE3	SE4	SE5	SE6	SE7	SE8	SE9	SE10
PLATYHELMINTHES										
Neppia montana	31	2	34	14	2					
ANNELIDA										
Stylodrilus sp.	46	121	112	104	30			112	80	497
Pristina sp.	40			60		20	20	32		
Lumbriculus variegatus		31	32		44		84		62	
Telmatodrilus multiprostatus						40				
Nais sp.							24			
MOLLUSCA										
GASTROPODA										
Potamopyrgus antipodarum	34	5	191	4	7	7		36		14
CRUSTACEA										
Paracalliope sp.		846		725	1328	598	92	5	95	120
P. subterraneus	873		1732		620					109
Austridotea benhami			45	2						
INSECTA										
EPHEMEROPTERA										
Coloburiscus humeralis						209	7	11		
Nesameletus sp.						2	13			
Neozephlebia scita								2		
Deleatidium spp.	481	124	1764	58	148	40	142	167	146	151
Austroclima jollyae	106	25	36		2	18	4		16	40
PLECOPTERA										
Stenoperla prasina		13	5	7	13	9	7	4		
Austroperla cyrene	5	16	32	13	2	74	25	18	11	13
Zelandoperla decorata	2	13	2		7		29	81	13	
Zelandobius confusus	20	65	191	43	7	14	20	16	13	95
Zelandobius furcillatus				2						
Spaniocerca zwicki						4	4	4		
Cristaperla fimbria						29	7		22	
Megaleptoperla diminuta	4	5	50	2			7	11	22	5
Megaleptoperla grandis								4		
MECOPTERA										
Nannochorista philpotti			4				11		2	
COLEOPTERA										
Elmidae							5	142	4	
Scirtidae	2		5		14	20	7			
Hydrophilidae	2			4						
DIPTERA										
Limonia nigrescens				2			5			
Eriopterini sp.			4	7			9	13	9	22
Nothodixa sp.	27		52	54	13		2	2		4
Diamesini sp. A.	12	3	49	16	17				59	19
Naocladius sp.	12									
Pentaneuriini sp.	5	8								

	SE1	SE2	SE3	SE4	SE5	SE6	SE7	SE8	SE9	SE10
Cricotopus sp.		3								
Paucispinigera approximata				16		112	704			19
Eukiefferiella sp.				15	17			34		
Polypedilum sp.								34	58	
Simuliidae		14				2	81	52	2	2
Empididae sp. B (hairy)	4	2	5			4	7		5	16
Empididae sp. D								7		
Paralimnophila skusei			5			2	5	5	2	2
?*Molophilus* sp.	2	2			2					2
Aphrophila neozelandica								2		
TRICHOPTERA										
Hydrobiosella stenocerca		81	18	58	38	11	2	83	2	
Hydrobiosis sp.	11	4		5	2	2			4	
Hydrobiosis silvicola	2		2						9	5
Hydrobiosis parumbripennis								2		
Psilochorema nemorale	5	2		11	2	29	27		14	23
Costachorema sp.								2		
Costachorema callista	4									
Costachorema psaroptera							7			
Helicopsyche spp.								2		
Rakiura vernale	5	5	7	16	4					
Hudsonema amabilis									2	
Oeconesus sp.						2	4			
Total density	1735	1390	4377	1238	2319	1248	1361	881	654	1158
Total taxa	24	22	23	23	21	22	29	26	24	19

Banks Peninsula Ecoregion (PE)

	PE1	PE2	PE3	PE4	PE5	PE6	PE7	PE8	PE9	PE10
PLATYHELMINTHES										
Neppia montana	234		34	162	16		95	13	9	4
Cura pinguis						18				
ANNELIDA										
Pristina spp.	2			50						86
Telmatodrilus multiprostatus	5	109						8		
Nais sp		80					20	10	95	
Stylodrilus spp.			126		31	212				
Lumbriculus variegatus				30					80	540
Limnodrilus hoffmeisteri				102			33			
Slavina sp.									30	
MOLLUSCA										
Potamopyrgus antipodarum	2	122	29	137	2	193	2	70	13	20
Sphaerium novaezelandiae				2		9		2		
CRUSTACEA										
Chiltonia sp.			5	2		2				
INSECTA										
EPHEMEROPTERA										
Coloburiscus humeralis	403	36	135	146	104	121	409	18	607	61
Nesameletus sp.	38	2	2	22			49	2		
Neozephlebia scita	85		56	23	68	11	5		50	
Deleatidium spp.	218	333	675	263	126	158	272	311	400	25
Austroclima jollyae	18			11						
PLECOPTERA										
Stenoperla prasina				61			4		2	
Austroperla cyrene	27		2	13			4	4	2	
Acroperla trivacuata	7		4				2			
Zelandoperla decorata					4					
Zelandobius confusus				2						
Zelandobius furcillatus	5	36		63			2	2	52	
Zelandobius unicolor		5		32		2		2	22	
MEGALOPTERA										
Archichauliodes diversus	4	4	11		11	14	27	16	4	2
MECOPTERA										
Nannochorista philpotti										4
COLEOPTERA										
Elmidae						2				2
Scirtidae				2						
Hydrophilidae	2								2	2
DIPTERA										
Nothodixa sp.	2	2	4							4
Macropelopiini	20	66			230	30	25	70	100	300
Polypedilum spp.	11	60				43		90	170	400
Eukiefferiella spp.		50	80	105	200		10	121	200	

	PE1	PE2	PE3	PE4	PE5	PE6	PE7	PE8	PE9	PE10
Naocladius spp..			74							
Orthoclad sp			100							
Diamesini sp. A				100						
Maoridiamesa					203	39		70		384
Cricotopus					400	43	10	40		
Simuliidae ungulatum		4	36	5	4	2142	43	5125	11	14
Tanyderidae		2	2	4	5	4	4	7		
Empididae sp. A										4
Empididae sp. B (hairy)	5			5						
Muscidae			2							4
Paralimnophila skusei				7						
Aphrophila neozelandica	2	2				14	13	7		
Psychodidae										5
Neocurupira chiltoni		4			9	122	25			
TRICHOPTERA										
Aoteapsyche colonica	13	29	83	32	23	112	40	4	5	
Polyplectropus puerilis							2			5
Hydrobiosella stenocerca	2	5	9	32			13			
Hydrobiosis sp.				4	4	16	9		2	16
Hydrobiosis silvicola	11			11			2			
Hydrobiosis parumbripennis		2	7		38	43		18		36
Hydrobiosis frater					2					
Psilochorema sp.			11							
Psilochorema bidens	5	32	70	2	22	54		27	2	9
Costachorema callista							9	7		2
Olinga feredayi	31	31	61		61	216	47	20	38	47
Helicopsyche spp.			4	2	74	65	4	7		2
Pycnocentria evecta	5			2	79					
Pycnocentrodes spp.					14					
Hudsonema amabilis				2						
Oeconesus sp.		2		18	2				7	4
Philorheithrus agilis	4		2	4			2			4
Total density	1161	1018	1624	1456	1655	3764	1182	6071	1903	1986
Total taxa	26	23	26	34	25	26	29	26	23	27

High Country Ecoregion (HC)

	HC1	HC2	HC3	HC4	HC5	HC6	HC7	HC8	HC9	HC10
PLATYHELMINTHES										
Neppia montana	7	70		36	45	5		45	11	31
ANNELIDA										
Nais sp.	80		1			256	15	65		
Stylodrilus sp.	22	52				20			18	18
Pristina sp.		50								
Telmatodrilus multiprostatus		60				80		70	20	20
Limnodrilus hoffmeisteri			3	47			10			
Lumbriculus variegatus				30	250					
MOLLUSCA										
Potamopyrgus antipodarum	72	2014	22	41	5	2	4	515	1438	13
Gyraulus spp.		4								
Sphaerium novaezelandiae		2								
CRUSTACEA										
Ostracoda	9	5			23			2		4
INSECTA										
Collembola					4					
EPHEMEROPTERA										
Coloburiscus humeralis			41	117	74		18	23	5	97
Nesameletus sp.			22			2				
Neozephlebia scita				52						
Deleatidium spp.	729	1668	1523	1975	695	4021	594	572	648	785
Austroclima sepia								2		
PLECOPTERA										
Stenoperla prasina			11			2				4
Austroperla cyrene	2									
Acroperla spiniger				2						
Acroperla sp. A	18									
Zelandoperla decorata	2	2	14	13	45	83				
Zelandobius confusus						22				
Zelandobius furcillatus	5									
Zelandobius unicolor					4					
Zelandobius pilosus	106				27	23				
Spaniocerca zelandica			2	9	4					
Cristaperla fimbria			2							
MEGALOPTERA										
Archichauliodes diversus	7	2	38	43	35	14	94	2		50
COLEOPTERA										
Elmidae	54	99	25	4	47	256	45	32	23	245
Scirtidae	2							4	4	

	HC1	HC2	HC3	HC4	HC5	HC6	HC7	HC8	HC9	HC10
DIPTERA										
Limonia nigrescens								27	7	
Eriopterini sp.	2		31		2	31			2	23
Nothodixa sp.								2		2
Tabanidae										2
Cricotopus sp.		85	232				70			
Diamesini sp. A.				40	100					
Maoridiamesa sp.	895	167	400		100	80	70	800	120	120
Polypedilum sp.				40						70
Eukiefferiella sp.		85	200			69	180		68	69
Orthoclad sp.			200					293	60	
Paucispinigera approximata				33						
Macropelopiini sp.					144	80				
Tanytarsus sp.						80				70
Naocladius sp.									60	
Simuliidae	5	1940	52	34	178	326	41	36	16	491
Tanyderidae							2		2	
Empididae sp. A	5	2			11	52			4	2
Empididae sp. B (hairy)										
Empididae sp. C (elong)						2	4			
Muscidae		11				7	2	41	25	
Paralimnophila skusei	14									
Aphrophila neozelandica	11	59	72		18	14				11
Ceratopogonidae										
TRICHOPTERA										
Aoteapsyche colonica	592	1237	212	79	367	349	185	27	2	270
Polyplectropus puerilis				7						
Hydrobiosella stenocerca	4			25		5	4	4		
Hydrobiosis sp.	11	32	18	5	9	97	41		9	81
Hydrobiosis parumbripennis	131	25	7	2	85	18	45	13		58
Hydrobiosis charadraea							2			
Psilochorema sp.			4						4	
Psilochorema nemorale	13	2	54	11	11	11	13	7	13	68
Psilochorema bidens	9			20	4					2
Costachorema sp.	2		11	4						
Costachorema xanthoptera				2	2					
Neurochorema confusum			7	4						
Olinga feredayi	23	182	297	115	536	99	212	50	54	1499
Conuxia gunni	4					2	88			
Helicopsyche spp.		11	29	441	11		81			14
Pycnocentria evecta	25	574		4	9	9	25	50	87	211
Pycnocentrodes spp.		119	263	18	4	4		5	7	266
Oxyethira albiceps	4				5	4	4		2	
Hudsonema amabilis				2						

	HC1	HC2	HC3	HC4	HC5	HC6	HC7	HC8	HC9	HC10
Oeconesus sp.										
Philorheithrus agilis		31			13			36	16	
Beraeoptera roria						9	2			
Zelolessica cheira										2
Zelandopsyche ingens										
Total density	2865	8590	3793	3233	2883	6140	1851	2723	2725	4598
Total taxa	31	28	30	30	33	37	26	26	28	31

Southern Plains (SL)

	SL1	SL2	SL3	SL4	SL5	SL6	SL7	SL8	SL9	SL10
PLATYHELMINTHES										
Neppia montana	7	29	34	9	31	4	5	45	20	4
ANNELIDA										
Stylodrilus sp.	3884		304	151	98		488	1220	1598	
Nais sp.		2205								
Lumbriculus variegatus		1020	200			493		1030		1010
Telmatodrilus multiprostatus					68					102
Nematode								7		
MOLLUSCA										
Potamopyrgus antipodarum	18398	4169	1588	495	882	1080	3661	412	14704	1213
Gyraulus spp.	5	27	92			2				
Sphaerium novaezelandiae	369	295	52	2		68	13	63	20	2
Physa acuta	4	128	437	29		20	106	13	38	299
CRUSTACEA										
P. caeruleus	20	4			29				2	
Paracalliope sp.					230	2		574		949
Ostracoda	1217	522						130	7	324
INSECTA										
Xanthcnemis sp.		13								
Sigara sp.		11						85	13	
EPHEMEROPTERA										
Coloburiscus humeralis					113					
Deleatidium spp.			14	337	338	7	2			
PLECOPTERA										
Austroperla cyrene					14					
MEGALOPTERA										
Archichauliodes diversus				9	7					
COLEOPTERA										
Elmidae			40	277		634	139	2	184	205
DIPTERA										
Limonia nigrescens	2									
Eriopterini sp.					2					
Naocladius sp.	98									60
Eukiefferiella sp.	98	25	1011	135		34	148	68		50
Cricotopus sp.								68	221	
Diamesini sp. A.					20					
Maoridiamesa sp.			200	137	32					
Polypedilum sp.										60
Macropelopiini sp.										66
Simuliidae		4	688	25	20	11		2	2	2
Muscidae			4	9	5		2		2	4
Aphrophila neozelandica				4	14					

	SL1	SL2	SL3	SL4	SL5	SL6	SL7	SL8	SL9	SL10
TRICHOPTERA										
Aoteapsyche colonica				823	103					
Hydrobiosis sp.			14			22	27			7
Hydrobiosis parumbripennis			2	47	7	32	14		4	
Psilochorema bidens	2		9	2	34	4			11	
Costachorema sp.					7					
Pycnocentria evecta				25	2		2			
Pycnocentrodes spp.				4	11					
Oxyethira albiceps	11		5	2		4	7		14	2
Hudsonema amabilis			16	9		142	2		1067	
Total density	24115	8452	4710	2531	2067	2844	4616	3719	17907	4359
Total taxa	13	13	18	20	22	16	14	14	16	17

Appendix 4. Water chemistry conditions for the 100 streams in 10 ecoregions

	pH	Cond ($\mu S\ cm^{-1}$)	Alk ($mg\ l^{-1}\ CaCO_3$)	Na	K	Ca	Mg	Fe	Mn ($mg\ l^{-1}$)	Al	Cl	NO_3-N	SO_4	PO_4-P
CO1	7.0	63.3	33.1	16.60	2.16	9.24	2.08	1.26	0.00	0.02	11.85	0.00	2.08	0.14
CO2	7.1	55.7	36.2	4.49	1.12	9.58	1.94	1.43	0.00	0.02	15.13	0.06	1.63	0.04
CO3	7.1	76.8	43.4	6.01	0.30	13.63	2.14	0.91	0.00	0.02	12.58	0.13	1.74	0.05
CO4	7.2	96.5	49.3	8.90	3.62	12.95	2.42	0.64	0.00	0.03	7.28	0.03	2.11	0.09
CO5	7.3	55.5	33.1	4.30	0.42	8.87	1.59	0.19	0.00	0.01	10.03	0.00	1.85	0.05
CO6	7.8	62.2	36.5	4.92	0.59	11.74	1.54	0.00	0.00	0.00	13.63	0.16	1.69	0.00
CO7	7.3	33.2	30.0	2.91	0.36	4.61	0.86	0.00	0.00	0.00	4.98	0.28	0.77	0.05
CO8	6.8	38.0	22.0	3.40	0.39	5.37	0.95	0.15	0.00	0.00	9.73	0.01	0.55	0.00
CO9	7.4	91.0	50.3	6.83	1.69	12.57	2.12	0.27	0.02	0.01	11.88	0.18	1.80	0.00
CO10	7.6	43.6	24.8	4.09	0.81	6.29	1.38	0.12	0.02	0.01	9.35	0.00	1.74	0.05
PE1	7.5	126.0	31.4	17.54	1.07	2.70	2.12	0.34	0.00	0.05	38.49	0.31	0.76	0.00
PE2	7.4	116.0	28.6	13.10	0.99	3.34	1.79	0.13	0.00	0.01	27.63	0.05	1.29	3.09
PE3	7.3	184.0	53.8	22.26	0.89	5.29	2.34	0.27	0.00	0.01	17.73	0.25	1.81	0.00
PE4	7.2	151.0	41.0	14.33	0.76	6.44	2.28	0.04	0.00	0.01	27.13	0.05	1.67	0.03
PE5	7.2	121.0	28.6	16.11	1.07	3.69	1.80	0.28	0.00	0.01	25.75	0.31	1.34	0.10
PE6	7.5	126.0	32.4	20.24	1.32	4.72	1.88	0.34	0.00	0.01	22.03	0.64	1.48	0.07
PE7	7.4	141.0	28.6	14.50	1.09	3.51	2.75	0.00	0.00	0.02	24.80	0.67	2.00	0.05
PE8	7.1	127.0	29.3	10.75	0.80	3.28	2.00	0.05	0.00	0.02	52.09	0.05	1.86	0.00
PE9	7.1	122.0	32.1	15.75	1.03	3.71	2.75	0.01	0.00	0.02	22.51	0.20	1.97	0.00
PE10	7.0	120.0	29.3	10.09	0.85	3.65	1.88	0.61	0.04	0.02	20.70	0.04	4.61	0.07
EC1	7.1	218.0	42.7	30.25	2.93	11.87	6.00	0.00	0.00	0.02	11.87	3.18	0.92	0.00
EC2	6.3	166.0	33.6	13.00	2.87	9.97	4.50	0.18	0.00	0.02	15.09	2.85	0.89	0.00
EC3	6.5	237.0	42.7	16.75	2.86	11.14	6.50	0.19	0.00	0.02	17.66	3.54	0.99	0.00
EC4	6.3	182.0	41.6	14.25	2.66	15.13	4.50	0.00	0.00	0.02	20.19	2.50	1.08	1.89
EC5	7.7	85.0	24.9	4.500	0.86	9.78	2.00	0.01	0.00	0.02	2.64	2.32	0.68	0.00
EC6	7.4	208.0	27.6	20.83	2.64	7.35	2.33	0.43	0.00	0.02	39.25	3.90	2.48	0.00
EC7	7.0	123.3	29.9	5.26	0.99	16.70	1.53	0.26	0.00	0.07	8.60	2.72	2.68	0.00
EC8	6.9	76.8	18.3	2.25	0.78	10.48	1.02	0.48	0.01	0.01	7.23	1.86	1.77	0.00
EC9	7.4	64.7	15.4	1.90	0.42	9.00	0.89	0.35	0.01	0.27	7.55	2.29	1.50	0.15
EC10	7.2	57.0	12.8	3.72	1.47	3.96	0.66	0.17	0.01	0.18	0.54	2.65	0.64	0.00
SA1	7.9	25.8	12.4	1.11	0.29	5.82	0.41	0.00	0.00	0.01	4.42	0.01	2.37	0.00
SA2	7.3	27.7	12.4	1.30	0.39	6.20	0.22	0.00	0.00	0.02	1.47	0.08	2.59	0.00
SA3	6.8	36.7	22.7	1.11	0.75	9.35	0.48	0.00	0.00	0.00	1.04	0.00	1.82	0.08
SA4	7.0	43.7	27.3	1.32	0.47	9.95	0.76	0.00	0.00	0.00	0.44	0.00	2.17	0.00
SA5	7.4	57.3	3.6	1.73	0.75	14.13	0.91	0.00	0.00	0.01	0.69	0.00	2.42	0.00
SA6	6.5	13.8	3.6	1.39	0.68	2.82	0.26	0.00	0.00	0.00	1.45	0.00	1.55	0.00
SA7	6.0	5.0	1.8	0.87	0.28	2.39	0.14	0.02	0.00	0.00	0.71	0.00	0.22	0.00
SA8	6.0	7.7	2.2	0.53	0.28	0.79	0.08	0.00	0.00	0.00	0.76	0.00	0.29	0.00
SA9	7.1	30.3	17.6	1.18	0.52	7.68	0.26	0.00	0.00	0.00	0.86	0.00	1.98	0.00
SA10	7.2	35.8	18.7	13.2	0.61	7.45	0.31	0.00	0.00	0.00	4.06	0.00	2.07	0.00
HC1	7.6	46.3	25.5	2.93	0.75	5.32	1.03	0.01	0.00	0.00	1.23	1.96	0.03	0.00
HC2	7.8	47.3	29.7	4.87	3.05	18.30	1.31	0.15	0.15	0.00	2.20	0.01	2.93	0.04
HC3	8.0	175.0	53.5	4.08	0.94	8.90	1.56	0.26	0.02	0.00	9.07	0.00	1.79	0.00
HC4	8.1	136.0	53.1	6.23	0.85	15.20	3.60	0.14	0.02	0.00	1.81	0.14	2.54	0.04
HC5	8.1	59.0	41.7	9.90	1.18	13.53	3.30	0.30	0.03	0.02	20.01	0.07	2.33	0.07
HC6	8.1	32.4	21.1	6.55	1.20	12.86	2.60	0.00	0.02	0.01	3.91	0.01	2.48	0.00

	pH	Cond ($\mu S\ cm^{-1}$)	Alk (mg l^{-1} $CaCO_3$)	Na	K	Ca	Mg	Fe	Mn (mg l^{-1})	Al	Cl	NO_3-N	SO_4	PO_4-P
HC7	8.0	40.0	26.2	2.51	0.53	8.21	0.84	0.09	0.00	0.00	2.76	0.02	2.04	0.00
HC8	7.7	60.2	40.7	4.45	1.17	5.75	1.19	0.18	0.02	0.00	5.94	0.00	0.93	0.00
HC9	7.7	54.1	35.9	5.08	0.80	11.58	1.56	0.00	0.02	0.01	16.43	0.00	2.69	0.00
HC10	7.6	33.0	21.7	4.35	0.85	9.91	1.54	0.04	0.02	0.01	15.56	0.00	1.84	0.61
SE1	7.1	219.0	32.8	36.39	2.66	4.39	5.90	0.19	0.03	0.03	56.63	2.03	3.84	0.00
SE2	7.3	183.0	27.9	31.07	2.15	3.95	5.40	0.78	0.16	0.16	51.38	0.16	3.29	0.00
SE3	7.0	237.0	20.7	44.21	2.79	3.34	5.60	0.10	0.02	0.02	84.20	0.14	3.83	0.71
SE4	7.1	188.0	20.4	34.26	2.88	3.06	4.20	0.04	0.05	0.05	56.33	0.17	2.66	0.00
SE5	7.2	163.0	19.3	28.42	1.84	3.26	3.80	0.32	0.04	0.04	53.90	0.14	2.91	0.00
SE6	7.5	170.0	20.7	28.84	2.56	4.32	4.10	0.09	0.03	0.03	50.55	0.07	3.06	0.00
SE7	7.1	160.0	21.7	24.21	2.36	4.08	3.80	0.09	0.01	0.01	43.88	0.57	2.91	0.00
SE8	7.2	174.0	24.1	28.57	3.27	4.08	4.10	0.07	0.01	0.01	47.65	0.08	3.13	0.00
SE9	6.8	183.0	19.3	32.97	3.53	2.86	4.50	0.50	0.05	0.05	56.33	0.17	3.49	0.00
SE10	6.9	193.0	29.3	34.09	2.38	4.23	4.90	0.30	0.03	0.03	56.0	0.14	3.62	0.00
NE1	7.7	149.0	171.0	8.28	0.67	3.90	3.10	0.00	0.02	0.01	17.15	0.39	9.67	0.00
NE2	7.5	86.8	141.0	7.55	0.60	3.63	2.30	0.00	0.01	0.00	13.75	0.11	4.57	0.00
NE3	7.0	53.7	72.6	7.29	1.41	1.20	0.46	0.10	0.00	0.00	14.63	0.29	3.74	0.00
NE4	7.2	63.8	93.3	6.62	1.33	1.91	0.70	0.00	0.00	0.01	7.79	0.39	2.49	0.00
NE5	7.5	165.0	134.0	7.70	0.95	3.16	1.68	0.06	0.00	0.02	16.37	1.14	5.31	0.00
NE6	7.6	80.9	130.0	7.62	0.68	2.68	1.59	0.00	0.03	0.02	31.70	1.98	3.41	0.00
NE7	7.4	71.5	85.5	8.20	0.69	2.25	1.96	0.01	0.01	0.02	12.54	0.74	2.79	0.00
NE8	7.7	106.0	157.0	4.49	0.76	2.12	3.00	0.00	0.00	0.06	26.80	1.19	2.30	0.00
NE9	7.2	82.6	84.6	2.69	0.63	2.72	1.47	0.00	0.01	0.04	3.460	1.03	1.70	0.00
NE10	6.9	42.7	67.4	7.50	0.68	2.72	0.62	0.09	0.00	0.02	2.410	3.44	1.74	0.00
SL1	6.4	299.0	39.0	47.47	2.78	7.76	7.70	0.00	0.00	0.00	64.75	0.10	4.45	0.00
SL2	7.0	240.0	80.0	20.21	1.92	21.43	8.40	0.69	0.01	0.01	11.35	0.42	4.54	0.00
SL3	7.1	132.0	52.8	12.89	1.56	8.63	5.90	0.52	0.01	0.01	1.38	0.13	2.50	0.00
SL4	7.3	68.40	21.7	7.49	1.08	5.46	2.70	1.61	0.04	0.04	1.95	0.00	1.62	0.00
SL5	6.9	97.40	38.0	9.17	0.43	8.88	3.50	0.32	0.00	0.00	9.73	0.00	0.62	0.00
SL6	8.0	178.0	75.2	15.20	1.00	15.41	8.00	0.74	0.01	0.01	24.10	0.02	2.94	0.00
SL7	8.5	134.0	27.6	15.32	0.66	6.03	4.10	0.40	0.01	0.01	18.80	0.03	2.02	0.00
SL8	7.1	196.0	34.6	29.37	2.26	7.17	4.80	0.46	0.01	0.01	49.80	0.09	3.78	0.00
SL9	6.8	173.0	27.9	24.27	1.24	6.58	4.10	0.21	0.01	0.01	48.67	0.08	3.79	0.00
SL10	8.1	466.0	235.0	25.96	1.24	120.2	8.20	0.41	0.01	0.01	37.76	0.07	2.99	0.00
NN1	6.3	28.4	9.3	3.64	0.30	1.42	0.60	0.03	0.02	0.25	1.60	0.00	1.25	0.04
NN2	6.2	27.9	8.9	3.96	0.49	1.95	0.60	0.00	0.02	0.06	53.15	0.04	1.15	0.04
NN3	7.2	48.5	77.7	5.34	1.02	4.18	1.00	0.00	0.00	0.01	53.72	0.43	0.84	0.06
NN4	7.2	45.4	85.5	4.63	0.82	4.26	1.40	0.00	0.00	0.01	51.95	0.33	1.29	0.07
NN5	7.1	38.5	72.7	4.64	0.74	2.25	1.40	0.00	0.00	0.01	52.75	0.04	1.48	0.05
NN6	6.7	98.3	47.9	24.10	1.48	1.28	4.20	0.00	0.00	0.14	58.21	0.46	2.72	0.00
NN7	6.7	143.0	45.4	7.47	0.79	1.70	1.09	0.45	0.00	0.25	61.27	0.07	5.66	0.04
NN8	6.8	73.6	44.0	2.87	0.29	4.00	2.90	0.37	0.00	0.01	43.34	0.00	5.97	0.00
NN9	7.7	179.0	368.0	3.01	0.26	54.40	3.60	0.00	0.01	3.48	51.99	0.00	3.48	0.00
NN10	7.8	75.5	144.0	2.55	0.25	17.32	3.60	0.00	0.00	1.03	58.06	0.00	1.03	0.00
WD1	6.5	37.2	5.2	1.82	0.50	2.47	0.50	0.14	0.00	0.10	2.10	0.01	0.13	0.00
WD2	5.9	23.1	2.9	1.90	0.61	1.62	0.43	0.03	0.00	0.19	1.73	0.00	0.070	0.00

	pH	Cond ($\mu S\ cm^{-1}$)	Alk ($mg\ l^{-1}\ CaCO_3$)	Na	K	Ca	Mg	Fe	Mn ($mg\ l^{-1}$)	Al	Cl	NO_3-N	SO_4	PO_4-P
WD3	6.4	62.7	13.6	2.32	1.74	5.81	0.65	0.00	0.00	0.04	11.37	0.01	0.56	0.00
WD4	4.9	30.5	0.8	2.18	0.92	1.88	0.39	0.00	0.00	0.30	4.24	0.00	0.19	0.00
WD5	4.7	27.4	1.4	1.99	0.54	0.96	0.34	0.05	0.00	0.24	6.55	0.00	0.09	0.00
WD6	7.0	37.7	8.4	3.58	0.91	1.10	0.54	0.29	0.00	0.02	0.48	0.09	0.44	0.03
WD7	7.5	88.10	27.3	6.14	2.10	3.91	1.89	0.46	0.00	0.02	0.56	0.10	0.59	0.00
WD8	6.4	44.9	9.8	5.24	1.22	3.16	0.59	0.52	0.00	0.03	2.18	0.15	1.21	0.00
WD9	4.8	19.0	1.4	1.63	0.17	0.24	0.18	0.09	0.00	0.24	13.30	0.15	0.55	0.04
WD10	6.2	39.5	12.5	2.24	0.82	3.19	0.64	0.46	0.01	0.01	0.99	0.16	0.60	0.00

Appendix 5. Macroinvertebrate faunas of streams included in the land use study near Hanmer Springs, sampled in four seasons between December 1992 and November 1993 (numbers m^{-2})

1. Native forested (*Nothofagus* sp.) streams

	Autumn				Summer				Spring				Winter			
	N1	N2	N3	N4	N1	N2	N3	N4	N1	N2	N3	N4	N1	N2	N3	N4
PLATYHELMINTHES																
Neppia montana			41	9					2	2	63	2			18	2
Cura pinguis ?													2			
ANNELIDA																
Lumbriculus variegatus																49
Pristina sp.	108								33		16		104	52	137	
Telmatodrilus multiprostatus				80												
Stylodrilus sp.		14		75		9	4		40			49				90
Limnodrilus hoffmeisteri																
Nais sp.			56													
MOLLUSCA																
Potamopyrgus antipodarum	2		25	54	2	2	5	5	5	4	13	16	2		14	18
Gyraulus spp.				2												
CRUSTACEA																
Ostracoda			2	11				2					2	4	4	
Chiltonia sp.																
INSECTA																
EPHEMEROPTERA																
Coloburiscus humeralis	27	122	216	54	40	146	69	67	36	284	99	131	25	23	68	369
Nesameletus sp.	2	5	65	7		10	4	4		7	36		2	9	22	2
Ameletopsis perscitus	2															
Neozephlebia scita	4	20	5	29		22			2	50		38		45	4	34
Zephlebia dentata									7							
Deleatidium spp.	185	25	457	378	151	85	211	225	272	56	535	270	198	4	481	536
Austroclima jollyae	14	18		2		27		9		45			4	7		22
Ichthybotus hudsoni				5												
PLECOPTERA																
Stenoperla prasina	16	4	38	34	4	4	7	13	14	2	36	5	9	11	43	25
Austroperla cyrene		5		2		25				14				13		
Acroperla trivacuata												5		2		
Acroperla spiniger				5	16	27	5	38		7		4				
Zelandoperla decorata	4		5	11	2		11		4		7	9	13	2		7
Zelandobius confusus					45								38		23	81
Zelandobius furcillatus	54	7	74	124	20	32		74		83			65	2	31	25
Zelandobius unicolor							108		169		212	56				
Spaniocerca zelandica	13	13		11		10	2		9	27	16	5	18	34	2	
Cristaperla fimbria						4								22		

	Autumn				Summer				Spring				Winter			
	N1	N2	N3	N4	N1	N2	N3	N4	N1	N2	N3	N4	N1	N2	N3	N4
Spaniocercoides sp.		4			5											
MEGALOPTERA																
Archichauliodes diversus		2	27	45		2	68	52			7	16	2		14	45
COLEOPTERA																
Elmidae	45	4	29	9	22	23	7	31	16	14	13	9	56	5	27	36
Scirtidae sp A.	2	4								7			2		2	
Scirtidae sp B.		4														
Ptilodactylidae		5		5	4	10		2	2			2	4	4		
Hydrophilidae		2														
DIPTERA																
Limonia nigrescens				2					2						2	
Eriopterini sp.	4			2		4					2	2				
Nothodixa sp.	2	2			2						2					
Eukiefferiella sp.	21				24	53		60				27	70		42	
Paucispinigera approximata	40		10											200		92
Polypedilum sp.													22			55
Orthocladiinae sp.					30											
Macropelopiini sp.		15	15		60	24			38	12	67			90		
Diamesinae sp.		30					74	230	22	10	70	40		14		
Maoridiamesa sp.				47	50			43	17							58
Simuliidae	2	4		9	43	5		135	20	20	22	113	4			36
Tanyderidae											2					
Empididae sp. A									2			4				
Empididae sp. B (hairy)	2	5		11	7	14		9		4			5	4		2
Empididae sp. C (elong)							2							4		4
Muscidae									2							
Paralimnophila skusei			2	4											2	
Aphrophila neozelandica			16	2				4	4		6	7			4	7
Ceratopogonidae					2			2								
Psychodidae													2			
Neocurupira sp.							2									
TRICHOPTERA																
Aoteapsyche colonica	13		5	7	10	2	13	11	7			7	8	2		32
Polyplectropus puerilis													4	11		
Hydrobiosella stenocerca	14	56	2		25	178		14		22	5	45	29		5	13
Hydrochorema crassicaudatum	7		2		5	2			2	2	2		2	2		
Hydrobiosis sp.		4	18					5	9	4		2			4	16
Hydrobiosis silvicola	9	5		5	4	27	2	13								
Hydrobiosis parumbripennis																
Hydrobiosis frater		2														
Psilochorema sp.					2											
Psilochorema nemorale	13	7	4		2					4						
Psilochorema bidens			11	20			4	5	2		4	5	11	14	14	13
Costachorema sp.												2	4			5
Costachorema brachyptera																
Costachorema callista						2	7	2	2							
Costachorema psaroptera																
Olinga feredayi	101	32	221	254	61	70	109	191	130	103	59	238		54		437
Helicopsyche spp.		2	124	109			67	32			119	62	126		76	65

	Autumn				Summer				Spring				Winter			
	N1	N2	N3	N4	N1	N2	N3	N4	N1	N2	N3	N4	N1	N2	N3	N4
Pycnocentria evecta	4		2		2		92	9		16				7		
Pycnocentria sylvestris		9		4					4	13						
Hudsonema amabilis	2	2		2			2	4								
Oeconesus sp.			4													
Beraeoptera roria													7		2	
Zelolessica cheira	13				25	16			14			1	58		9	2
Zelolessica meizon			2													
Zelandopsyche ingens										4				16		
Total density	756	421	1474	1429	680	808	779	1273	998	836	1422	1173	846	645	1224	2132
Total taxa	27	31	26	34	27	29	23	29	30	27	24	29	31	28	25	30

2. Exotic forest (*Pinus* sp.) streams

	Autumn				Summer				Spring				Winter			
	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
PLATYHELMINTHES																
Neppia montana	14	13	22	4					54	43	47	25	9	25	52	
Cura pinguis?																9
ANNELIDA																
Lumbriculus variegatus	5	10	29							12			72		13	
Pristina sp.							4				20	10		49	38	13
Telmatodrilus multiprostatus	4	12		5												
Stylodrilus sp.			29	4				7	68		7	5			27	
Nais sp.										29						30
MOLLUSCA																
Potamopyrgus antipodarum		52		110	32	95		40	7	7		20	11	5		18
Gyraulus spp.					2		2								4	
Sphaerium novaezelandiae																4
CRUSTACEA																
Ostracoda	14		22		18	13		2					7	2	14	9
INSECTA																
Collembola sp.				2					5							
EPHEMEROPTERA																
Coloburiscus humeralis	20	2	7		74	2	47		74	7			50	2	16	
Nesameletus sp.	29	14	29		25	14	18		4		13		40	7	63	
Neozephlebia scita	7		16	176				79	4		4	25			45	137
Deleatidium spp.	54	47	191	70	258	187	608	49	230	68	373	157	155	65	383	180
PLECOPTERA																
Stenoperla prasina	35	32	77		205	70	47		40	9	4	2	158	54	47	2
Austroperla cyrene	14	63	81	90	257	248	126	104	52	29	23	22	54	45	77	59
Acroperla trivacuata										2				2		
Acroperla spiniger					18	5	2		13	7						
Zelandoperla decorata		2				4	4			2			5	2	2	
Zelandobius confusus													20	14	13	
Zelandobius furcillatus	20	23	92		77	4	198	2					7		13	
Zelandobius unicolor									153	18	104					
Spaniocerca zelandica	9	2	2	4	9	29	14	14	13	11	4	4		4	4	9
Spaniocercoides sp.											4					
MEGALOPTERA																
Archichauliodes diversus													2			
COLEOPTERA																
Elmidae															2	4
Scirtidae								2								

	Autumn				Summer				Spring				Winter			
	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4	E1	E2	E3	E4
Ptilodactylidae	24	5		36	9	36		14	7	13		41	11	7	2	61
Hydrophilidae				2		4			2							
DIPTERA																
Limonia nigrescens	2															
Eriopterini sp.		2	5		2	7	4		11	11			9	4	2	
Nothodixa sp.								22				4				2
Eukiefferiella sp.													39			130
Paucispinigera approximata	22	11			44				26		28	190	94	99	51	314
Polypedilum sp.					30											
Orthocladiinae sp.				4												
Diamesini sp A.			11						44	5	10					
Macropelopiini sp.				5		70	25	83				96			50	
Simuliidae					11				7		4	2		5	4	106
Empididae sp. B (hairy)	5	2					2		5				2			
Empididae sp. C (elong)					2											
Paralimnophila skusei	4	7	7		5	7	11		2	2	14	5	5	5	5	
Hexatomini								2								
Ceratopogonidae						2						4				
TRICHOPTERA																
Aoteapsyche colonica	20	2			2				9		4		2	5		
Polyplectropus puerilis	2	2			2			14	4			23	5	2		4
Hydrobiosella stenocerca	227	131			74	5			23	16	2		14	58	2	
Hydrochorema crassicaudatum	2				7		2		2	4			2	2		
Hydrobiosis sp.		2			4		4	2	11	2			5	4		2
Hydrobiosis silvicola	2	2							5				2			
Psilochorema nemorale				11				9				4			2	14
Psilochorema bidens								2								
Olinga feredayi	23	13	5	9	20	20	11		18	5	5		13	13	11	5
Helicopsyche spp.	2	11		9	4	4		9	4	4		11	5	4	2	25
Pycnocentria evecta														4		
Pycnocentria sylvestris				14				5								4
Hudsonema amabilis			11		4					2						
Oeconesus sp.			4			2										
Philorheithrus agilis	2				9								2			
Beraeoptera roria											4					
Zelolessica cheira		2			23	31	11	2			2					
Philorheithrus agilis	11		11												23	
Alloecentrella sp.												2				
Total density	673	464	647	555	1227	857	1117	463	892	313	676	652	800	488	967	1141
Total taxa	14	16	10	12	20	19	17	16	15	13	19	17	13	16	16	21

3. Scrubland catchment streams

	Autumn				Summer				Spring				Winter			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
PLATYHELMINTHES																
Neppia montana	9		2						25		36		56		5	2
ANNELIDA																
Lumbriculus variegatus													81	47		
Pristina sp.									128			60			76	
Stylodrilus sp.				54			4	4		4	77	77			120	
Aulodrilus pluriseta															24	
MOLLUSCA																
Potamopyrgus antipodarum	7	25	50		5	34	43	5	7	22	41		9	9	31	
Gyraulus spp.				2												
CRUSTACEA																
Ostracoda				38				4				2				4
Paracalliope sp.							14								2	
INSECTA																
EPHEMEROPTERA																
Coloburiscus humeralis	11	4	144	99		31	121	4		41	117	396	4	49	193	157
Nesameletus sp.		7	2			5				22				22	9	
Ameletopsis perscitus							9									
Neozephlebia scita			29				23				52	4				14
Deleatidium spp.	414	625	535	2324	365	853	1705	1420	781	1523	1975	2502	1084	1413	2743	1627
Ichthybotus hudsoni			2													
PLECOPTERA																
Stenoperla prasina			14			4	5				11			2	4	
Acroperla spiniger												2	2			
Zelandoperla decorata		2			2			4	18	14	13		5		11	
Zelandobius furcillatus	2											4				
Zelandobius pilosus																4
Spaniocerca zelandica	32		2	2	5				5	2	9		20		2	
Cristaperla fimbria										2						
MEGALOPTERA																
Archichauliodes diversus	2	27	79		2	43	50	4	9	38	43	9		47	47	
COLEOPTERA																
Elmidae		92	2	31		137	2	34		25	4	22	9	52		2
Ptilodactylidae															2	
DIPTERA																
Eriopterini sp.	2	14				14	9	2	4	31			9			
Nothodixa sp.				14				2								
Eukiefferiella sp.	30	230			25	25	50	64		1132	113	40		40	12	60
Paucispinigera approximata			7												10	
Orthocladiinae sp.		157		5										44		
Macropelopiini sp.				4	35	47	80									70
Diamesini sp A.																

	Autumn				Summer				Spring				Winter			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Maoridiamesa sp.	44				30	52		60	18			32	38	100		
Simuliidae	18	22			41	140	7	14	13	52	34	65	22	49	11	25
Tanyderidae				2												
Empididae sp. A														4		
Empididae sp. C (elong)						2										
Muscidae		2			14		2	2								
Paralimnophila skusei	4				2		2	4	4							
Hexatomini						2							2			
Aphrophila neozelandica	49	25			22	83	7	2	54	72			32	126		
Ceratopogonidae							2							7		
Tabanidae						2	2	4								
Neocurupira hudsoni					2				2				5			2
TRICHOPTERA																
Aoteapsyche colonica	5	140	81	32	7	88	23	4	40	212	79	185	34	160	68	13
Polyplectropus puerilis				4			2	4			7	4				
Hydrobiosella stenocerca			2		2		72				25				31	
Hydrochorema crassicaudatum	2															
Hydrochorema tenuicaudatum													2			
Hydrobiosis sp.	11	11			7	14		7	5	18	5	2	22	9	4	11
Hydrobiosis silvicola														7		
Hydrobiosis parumbripennis		2			14	9	5	18		7	2	9		2	7	7
Hydrobiosis umbripennis																2
Hydrobiosis charadraea													5			
Hydrobiosis clavigera														2		
Hydrobiosis frater					9											
Psilochorema sp.										4						
Psilochorema nemorale		40	4	23	4	7		16		54	11	5				
Psilochorema bidens	25	7	5		4	2			4			2	9	27	4	20
Costachorema sp.										11	4					
Costachorema callista	4	2			14	2			2				9			
Neurochorema confusum		2				7				7	4			7		
Olinga feredayi	2	182	211		4	142	139	2	2	297	115	5		175	97	
Conuxia gunni									7							
Helicopsyche spp.		67	450	13		103	832	5		29	441	23		9	324	4
Pycnocentria evecta	5	200	45	162		140	68	117			4	112		671	83	236
Pycnocentria sylvestris													2			
Pycnocentria funeria								2								
Pycnocentrodes spp.		4		7		33	11	74		263	18	90		5	12	23
Hudsonema amabilis				182				36			2	58				11
Beraeoptera roria	2															
Oxyethira albiceps	2															
Total density	659	1889	1666	2949	615	2018	3289	1918	1125	3882	3122	3710	1461	3085	3932	2294
Total taxa	23	25	20	18	23	27	27	28	20	25	25	23	22	26	25	22

4. Pastoral catchment streams

	Autumn				Summer				Spring				Winter			
	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4
PLATYHELMINTHES																
Neppia montana										9	5		4	2		4
Cura pinguis?									2							
ANNELIDA																
Lumbriculus variegatus	40					189	356		203	473			517		212	259
Pristina sp.		64			5			194							200	
Telmatodrilus multiprostatus				200								639				
Stylodrilus sp.		60	223	169							164					
Slavina sp.														133		
Nais sp.	25															
NEMATODA				2		5	2									10
MOLLUSCA																
Potamopyrgus antipodarum	6548	434	4	383	4856	488		322	3231	52	1382		61	1604		454
Physa acuta	20	25	196		36	77	34	49			23	56		2	79	
Gyraulus spp.			45				2					14			9	
Sphaerium novaezelandiae		4			2											5
Lymnaea sp.						2	4			7		2	9			4
CRUSTACEA																
Ostracoda	9	38			72	2	25	18			2	14			14	122
INSECTA																
Collembola						13	4					4				
Sigara sp.												5				
Xanthocnemis zealandica				2							4	2		2		2
Culex sp.						2										
EPHEMEROPTERA																
Coloburiscus humeralis			2													
Neozephlebia scita			2													
Deleatidium spp.		38	2	427		2	2	5	16	52	117	31	392	2		61
PLECOPTERA																
Zelandobius confusus									4	2						
COLEOPTERA																
Elmidae		2				2					31				9	
DIPTERA																
Eukiefferiella sp.			100	323	9	41	200		400	800	100			20	92	144
Chironomus sp.							100									
Polypedilum sp.					6											
Orthocladiinae sp.	5			20						206		300			18	
Macropelopiini sp.		20			5									30		
Tanytarsus sp.							49									
Maoridiamesa sp.						110		126	223		82	503	648		70	
Simuliidae	149			36	4	45	27	54	9	4	59	43	126		119	49

	Autumn				Summer				Spring				Winter			
	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4	P1	P2	P3	P4
Muscidae			5			11	13	2	2			4	2		2	2
Paralimnophila skusei	2													2		
Aphrophila neozelandica	2															
Ceratopogonidae					4				2							
Sciomyzidae					2											
Stratiomyidae					2											
TRICHOPTERA																
Aoteapsyche colonica	2								4				2	4		
Hydrobiosis sp.		5			11			20				49				
Hydrobiosis silvicola			4													
Hydrobiosis parumbripennis					7		54	5		4	16		29	2	9	34
Hydrobiosis umbripennis					4	99	50	2			23	31			14	27
Psilochorema nemorale	2	14			4	22	61	40	5	47	27	7	10	11	4	22
Psilochorema bidens								4								
Pycnocentria evecta	1338	158	14		700	2			380		18		9	846	2	76
Pycnocentria funera										2						
Pycnocentrodes spp.	18	16			45	5			131	27	31			234		77
Hudsonema amabilis	247	47			7			4	5		23			95	2	27
Oxyethira albiceps	9	5		2	2	31	24	236		14	2	106	7	2	4	9
Zelolessica cheira								2								
Total density	8317	1079	1486	1280	5783	1148	1007	1083	4617	1697	2111	1810	1816	2991	850	1399
Total taxa	15	15	11	10	20	19	17	16	15	14	18	17	13	16	17	19

WD Westland Forest
SA Southern Alps
NN North-west Nelson Forest
NF Nelson Plains
NE North-east Nelson Forest
MP Marlborough Plains
HC High Country
EC East Coast Plains
PE Banks Peninsula
CO Central Otago
SL Southland Plains
SE South-east Forest